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Review

A Systematic Literature Review on Urban Resilience Enabled with Asset and Disaster Risk Management Approaches and GIS-Based Decision Support Tools

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Featured Application: This paper presents a review of literature on urban resilience, highlighting research gaps and suggesting solutions such as using asset and disaster risk management methods combined with GIS-based decision-making tools to improve resilience in urban areas. This can be applied in the field of urban planning and design, disaster risk management and asset management planning decisions to enhance the ability of cities and communities to optimally withstand and recover from disruptions.

Abstract: Urban Resilience (UR) enables cities and communities to optimally withstand disruptions and recover to their pre-disruption state. There is an increasing number of interdisciplinary studies focusing on conceptual frameworks and/or tools seeking to enable more efficient decision-making processes that lead to higher levels of UR. This paper presents a systematic review of 68 Scopus-indexed journal papers published between 2011 and 2022 that focus on UR. The papers covered in this study fit three categories: literature reviews, conceptual models, and analytical models. The results of the review show that the major areas of discussion in UR publications include climate change, disaster risk assessment and management, Geographic Information Systems (GIS), urban and transportation infrastructure, decision making and disaster management, community and disaster resilience, and green infrastructure and sustainable development. The main research gaps identified include: a lack of a common resilience definition and multidisciplinary analysis, a need for a unified scalable and adoptable UR model, margin for an increased application of GIS-based multidimensional tools, stochastic analysis of virtual cities, and scenario simulations to support decision making processes. The systematic literature review undertaken in this paper suggests that these identified gaps can be addressed with the aid of asset and disaster risk management methods combined with GIS-based decision-making tools towards significantly improving UR.

Keywords: urban resilience; Geographic Information System (GIS); asset management; risk management; decision making; sustainability

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1. Introduction

Urban settlements are expected to house more than 60% of the world's population by 2030. According to UN forecasts, there are already over 4 billion urban inhabitants worldwide, with more than 863 million unofficial residents in urban settlements. This number is projected to grow at a rate of over 1 million every 10 days [1]. Urban areas produce more than 75% of the global GDP and account for the majority of global energy consumption. Cities also contribute to 70% of global greenhouse gas emissions. Additionally, 90% of metropolitan areas are located on coasts, exposing a large portion of the worldwide population to disaster risks arising from climate change [2].

As urbanization continues to increase, tackling the problems associated with urbanization and climate change requires innovative sustainable solutions to enhance Urban Resilience (UR). UR is a concept that addresses the issues of urbanization and climate change in all its facets.

The study's relevance and significance can be found in the fact that natural hazards such as earthquakes, floods, windstorms, tsunamis, and volcanic eruptions pose a perpetual threat to the safe and effective functioning of critical infrastructures in a critical public service context [3]. These natural disasters have the potential to disrupt the flow of information and trade, as well as compromise security and safety [4]. This is particularly true in the current global economy, where supply chain interruptions are becoming increasingly common [5,6].

Implementing efficient urban resilience (UR) concepts requires a multidisciplinary approach that involves all relevant stakeholders. A long-term strategy is essential for achieving sustainable UR. To enhance resilience and prepare for natural disasters, cities must focus on building early warning systems, developing emergency operations plans, and implementing risk mitigation measures within their communities [7–9].

Enhancing Urban Resilience (UR) requires a range of solutions that can be implemented at different levels and by various stakeholders [10,11]. These solutions can include regulations, legislation, guidelines on technical issues such as building codes or land use planning, financing for services and critical infrastructure assets, and urban planning tools such as zoning plans. Additionally, partnerships between local authorities and various organizations can play an important role in implementing UR strategies [12,13].

In recent years, experts and politicians have been focusing on identifying the most effective techniques for dealing with natural disasters in cities. This has been driven by the increased frequency and severity of natural disasters due to climate change, and the need to better understand how cities can withstand these events and prepare for them [14–16].

The purpose of this review paper is to examine the major trends in Urban Resilience (UR) research and explore how management approaches, decision science methods and tools can support the achievement of the United Nations (UN) Agenda for Sustainable Development by increasing resilience in cities and communities. Additionally, the paper aims to identify research gaps and potential opportunities to enhance multidisciplinary UR decision-making processes.

This paper is divided into six sections. The introduction provides an overview of the motivation and scope of the review, as well as the objectives of the paper. The second section examines the background knowledge and relevant approaches and techniques that can impact UR, including how UR and sustainability can be enhanced through asset management and risk management approaches and decision science and support tools, specifically GIS-based tools, to improve the performance of assets and asset systems in cities during natural and man-made disasters. The third section details the methodology used to conduct the systematic review, including the PRISMA protocol, keywords, and selection of studies. The fourth section presents a bibliometrics and results analysis, including data visualization. The fifth section discusses the findings of the study and highlights research gaps and current trends, as well as uses natural language-processing techniques. The final section concludes the study and suggests areas for future research.

2. Background Knowledge

This section presents the background knowledge of two key conceptual constructs for maximizing and protecting the value of constructed assets during disaster risk events: asset management and risk management. Additionally, it highlights relevant decision-making support tools and analytical solutions that can be integrated to support the achievement of the United Nations 2030 Agenda for Sustainable Development's twin goals of creating resilient and sustainable cities. Figure 1 illustrates a conceptual framework for improving multidisciplinary decision-making towards sustainability and urban resilience. This framework is further explored in the following three sections: (1) resilience and sustainability of urban infrastructure and buildings; (2) asset and disaster risk management; (3) decision science support mechanisms and tools.

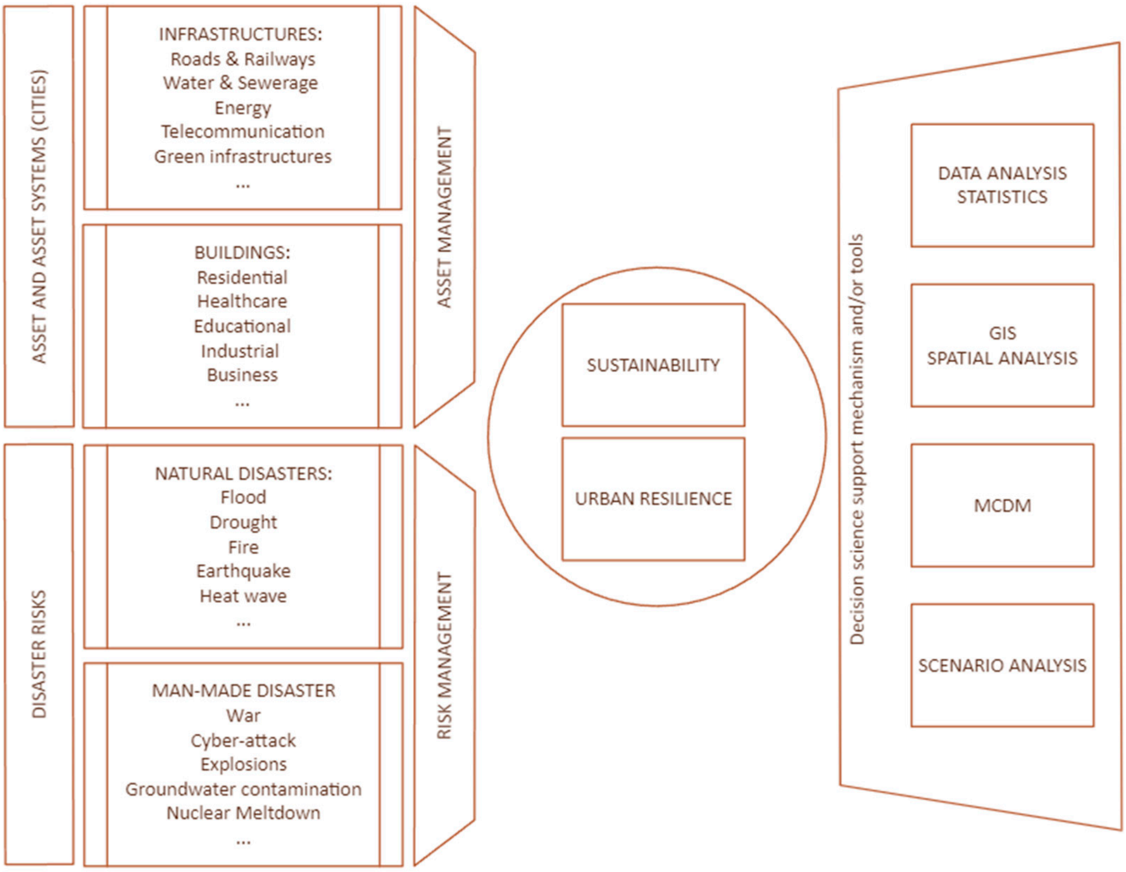

Figure 1. Background knowledge for improved multidisciplinary decisions towards sustainability and urban resilience.

2.1. Asset and Disaster Risk Management

An asset is a tangible or intangible item that has value or potential value to a person or organization [17]. Asset management, as defined by international standards, is the coordinated effort of an organization to maximize value from its assets by balancing risk, cost, opportunity, and performance throughout their lifecycles [18]. In the context of urban resilience, asset management is critical for preventing future unfavorable events and ensuring assets are prepared for them. Public and private sectors, as well as regional and state governments, must invest in asset resilience to achieve this [19,20].

The asset management approach plays a crucial role in allocating limited resources (people, money, time, natural resources, etc.) to initiatives that yield the greatest value for all stakeholders throughout the lifecycle of urban assets and systems. Many organizations worldwide have implemented Asset Management Systems (AMS) that comply with the ISO 55000 family of standards to develop consistent strategies and coordinate the delivery of resources and tasks to maximize profitability [21–23].

Asset management is a crucial component of risk management, as it addresses the financial and reputational risks associated with speculation. According to international standards on risk management (ISO 31000), risk is defined as "the effect of uncertainty on objectives" and risk management involves "coordinated activities to direct and control an organization with regard to risk." These standards provide guidelines for designing, implementing, and continually improving risk management processes throughout an organization [24].

The decision-making process in risk management involves assessing the appropriate level of risk for a certain choice and determining the steps to be taken in case of a risk event. Both risk management and asset management aim to ensure that resources are allocated to initiatives that benefit the community [25–27].

To build urban resilience, national and municipal governments must establish local disaster risk-management strategies to mitigate the impact of climate change [28]. This includes regularly reporting on small-scale onset hazardous occurrences that are not recorded in global catastrophe loss databases [29]. It is also crucial to acquire consistent data on losses from all dangers and underlying concerns.

However, the implementation of findings from the Habitat III Urban System Model may face obstacles due to a lack of transparency, flaws in urban governance, and constraints in financial and human resources. These factors can lead to socioeconomic evaluation biases and lower performance of urban resilience.

Vulnerability assessment is an important aspect of the climate risk assessment process, as it identifies potential disruption to the community caused by climatic impacts. Urban risk governance involves the diverse roles and responsibilities of different players in minimizing urban risks. The government plays a crucial role in developing national policies, implementing mitigation measures, and establishing emergency response procedures. Local governments also play a role in urban risk management through land-use planning, construction rules, disaster preparedness programs, and evacuation plans. Community members, including households and individuals, can also improve resilience by implementing disaster preparedness measures [30].

Private sector organizations play an important role in urban risk management, as they develop buildings or infrastructure projects that are sensitive to natural disasters. Civil society organizations provide input into public decision-making processes about policy implementation targeted at decreasing dangers for communities living in high-risk areas. International organizations, such as the United Nations, may also help countries with limited resources implement their policy agendas by providing financial assistance or technical expertise.

Both asset and risk management approaches offer critical processes for controlling and minimizing hazards in urban systems, and for improving the safety, reliability, and efficiency of assets and asset systems [31,32]. Resilient systems are built and utilized for recovery and adaptation rather than just resistance to the initial disturbance. Resilience thinking supports asset and disaster risk management by accelerating system recovery, especially when common risk management measures struggle to mitigate a disruption [33]. The importance of resilience as applied to urban infrastructure and buildings, and its role in achieving sustainable development goals, will be discussed in the next section.

2.2. Resilience and Sustainability of Urban Infrastructure and Buildings

Cities currently house more than half of the world's population, and this figure is expected to increase by 2.5 billion people by 2050, with the majority of this growth occurring in emerging nations [34]. While cities have traditionally been associated with wealth, progress, and opportunity, they are also facing unprecedented levels of inequality and poverty. Urbanization also has an impact on natural resources and ecosystems, as well as climate change mitigation efforts, due to the heavy reliance on fossil fuels for electricity in cities.

Natural catastrophes pose a significant threat to cities, as seen in the examples of Hurricane Katrina in 2005 and Hurricane Harvey in 2017, which resulted in significant loss of life and damage [35]. In order to improve resilience and sustainability in coastal regions, it is crucial to understand the vulnerability concepts and existing definition of vulnerability [36]. This section will focus on the importance of resilience and sustainability in urban infrastructure and buildings and will highlight measures that can be taken to enhance resilience in the face of natural disasters and climate change.

Beyond risk management, resilience management addresses the complexity of large interconnected systems and the unpredictability of future risks, particularly those related to climate change [33]. Resilience management includes: performing preparation planning and training, adhering to inspection and maintenance procedures and improving them (asset management), developing, executing, and upgrading risk management processes, revising design requirements in response to varied feedbacks, participating in various industrial associations, as well as standard committees and regulatory bodies, adopting resilience-based asset management principles and techniques in the face of deep uncertainty and different disruptive occurrences, and preparing for foreseeable global shocks to maintain economic sustainability and provide a sufficient service level to clients.

Recognizing the significance of resilience and sustainability in buildings and infrastructure is crucial, as both resilience and sustainability are essential in the face of climate change and its effects on the built environment. In this context, resilience refers to a structure's ability to survive disruptions such as floods, fire [37], and earthquakes and other natural disasters, whereas sustainability relates to the capacity of buildings and infrastructures to be environmentally sustainable [38,39].

Resilience is a system's ability to adapt to change while maintaining its fundamentally specified performance [40]. Resilient communities are able to endure, absorb, or recover quickly from catastrophic events such as floods [41–43], earthquakes [44], hurricanes [45] or heat waves [46] because they were constructed with hazard risks in consideration through integrated planning methods that handle several hazards concurrently.

UR refers to the quantifiable capacity of any urban system, together with its residents, to preserve continuity despite all shocks and pressures while constructively adapting and reforming toward sustainability [47]. A resilient city is one that evaluates, plans for, and takes action to cope to natural and man-made disasters, both predicted and unforeseen [48]. Resilient cities are better prepared to preserve development achievements and improve the lives of citizens.

Urban resilience's ultimate goal is to increase cities' capacities to recover from natural disasters. Efforts to achieve this goal are being made by various prominent actors, such as The World Bank Group, Global Facility for Disaster Reduction and Recovery, 100 Resilient Cities, UNISDR, C40, Inter-American Development Bank, Rockefeller Foundation, ICLEI, and Cities Alliance. The 7th World Urban Forum session in Medellin, Colombia in 2014 at UN-Habitat, known as the Medellin Collaboration, brought together influential players focused on developing resilience globally [49].

UN-Habitat, the Global Covenant of Mayors, and the Intergovernmental Panel on Climate Change also hosted the Cities and Climate Science Innovate4Cities Conference, which brought together approximately 200 gatherings and approximately 7000 participants from 159 countries to promote understanding and technology for urban climate policy [50].

The Medellin Collaboration developed a platform to assist regional authorities and relevant municipal experts in understanding the fundamental purpose of the wide range of tools and diagnostics created to test, evaluate, track, and enhance city-level resilience. These tools range from self-deployable quick evaluations to create an overall understanding and benchmark of a city's resilience, to action-oriented tools that require more advanced institutional, technical, and economic capacities to implement, and others that are designed to pinpoint and prioritize budget allocation.

The Rockefeller Foundation has developed the 100 Resilient Cities program to promote urban resilience, which is defined as the ability of individuals, communities, institutions, enterprises, and systems within a city to endure, adapt, and thrive in the face of recurrent pressures and severe disruptions [51–53]. The City Resilience Index (CRI), created by Arup and financed by The Rockefeller Foundation, is the result of five years of study and testing. It is a tool that helps cities understand and address these concerns in a systematic manner. The CRI has four main dimensions: (1) health and well-being, including minimum human vulnerability, a variety of livelihoods and job opportunities, and strong safeguards for human health and life; (2) economy and society, including economic sustainability, total security and the rule of law, and shared identity and citizen involvement; (3) infrastructure and environment, including decreased vulnerability and fragility, efficient delivery of key services, and reliable transportation and connectivity; (4) leadership and strategy, including integrated development planning, empowered actors, and efficient management and leadership.

Information interchange among critical infrastructures is essential for identifying interdependencies and enhancing their resilience. For example, DOMINO is a tool developed by the Centre Risque & Performance, Polytechnique Montréal (Québec, Canada) that enables multi-organizational collaboration and can aid in solving complex problems through knowledge sharing [54]. This tool can recognize the interrelations among critical infrastructures and simulate potential domino effects of their failure. This means that upstream work is done within major infrastructure organizations to encourage them to implement more strategic, holistic, and integrated asset, risk, and resilience management methods. Only then can successful and long-term collaboration among critical infrastructures be possible [55].

It is difficult or impossible to regulate highly interconnected systems, which are prone to breakdowns at all scales, posing major hazards to civilization even in the absence of external shocks. New vulnerabilities are emerging as a result of the growing interdependence of our energy, food, and water infrastructure, global supply chains, financial and communication systems, ecosystems, and climate [56].

However, it has also been argued that cities, despite being highly interconnected systems, are also resilient complex systems. For many years, cities have endured natural and man-made disasters and, in some cases, have even become more robust and resilient in the face of disasters [57]. However, there are new hazards and concerns for cities [58] that are expressed in Goals 9 and 11 of the 2030 Agenda for Sustainable Development of the United Nations (UN).

Urban sustainability and resilience are integral to achieving the United Nations' Sustainable Development Goals (SDGs) [59,60]. With an increasing global population and complex urban development demands, revolutionary solutions are needed to meet the challenges of urbanization and climate change [58,61–63].

Goal 9 of the 2030 Agenda for Sustainable Development of United Nation (UN) refers to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". This goal is a reminder that, when natural catastrophes strike, urban regions suffer more mortality and economic losses than rural areas because of the influx of population, structures, industries, and assets, including the densely interwoven infrastructures [64]. Megacities' interconnected infrastructures are vulnerable to cascading system failures such as in roads and railways, water and energy supply networks, telecommunication systems, sewage systems, and green infrastructures [65]. Governments and companies are being forced to recognize and handle the larger and more rapidly altering environment. One can for example consider the risks arising from the failure of energy, or communication, systems. Cascading failures introduce a new hazard potential that cannot be fully addressed by minimizing risks in single system components [66].

Furthermore, a significant portion of the global population explosion is concentrated in low-lying coastal cities, which are susceptible to urbanization and the effects of sea level rise and storm surge [67,68]. Goal 11 aims to make cities and settlements inclusive, safe, resilient, and sustainable to address the reality that over half of the world's population now resides in urban areas and to decrease the threat of natural disasters caused by urbanization. Climate change impacts such as extreme weather events can cause significant damage and economic loss across many locations. Smart city design can help reduce vulnerability to these disasters and the need for international collaboration on this issue is more important than ever.

Millions of people live in cities, which are complex asset systems. They are sources of economic development and job prospects, but are also some of our planet's most vulnerable areas in terms of climate change implications. As a result, this objective seeks to enhance people's lives by ensuring the sustainable management and control of cities' resources while lowering their environmental impact. This includes safeguarding human settlements against natural disasters (such as earthquakes or floods), reducing their vulnerability to disasters through risk reduction measures (such as better housing construction), ensuring access to clean water supply systems by promoting proper sanitation facilities (such as toilets), improving waste management services (including recycling), and making urban environments more resilient to extreme heat events such as droughts or floods [69].

Goal 11.1 covers Disaster Risk Reduction (DRR) as an essential component of social and economic development if growth is to be long-term. Several worldwide documents on disaster risk reduction and sustainable development have acknowledged this. As the first major worldwide framework for disaster risk reduction, the Yokohama Strategy and Plan of Action for a Safer World (1994) acknowledged the interdependence of sustainable development and disaster risk reduction [70]. Since then, this close interdependence has been continuously reinforced within key global agreements, ranging from the Millennium Development Goals to the Johannesburg Plan of Implementation (Johannesburg, September 2002), the "Hyogo Framework for Action (2005–2015)" and the "Future We Want" [71], the Sendai Framework for Disaster Risk Reduction [72], and the 2030 Agenda for Sustainable Development.

According to the United Nations International Strategy for Disaster Reduction, communities are becoming increasingly vulnerable to global climatic change consequences, particularly drought, floods, heat stress, severe rainfall events, and other natural disasters [61,73,74].

Hydro Quebec provides the example of an ice storm case study that motivated improvements in the mechanical strength of the grid infrastructure. New construction standards were established and vegetation around transmission and distribution lines was better controlled; the transmission and distribution system was reconfigured to increase the security of the energy sources and include backup sources of supply in the event of line failures [75].

Goal 11.2 relates to sustainable cities and human settlements. Cities currently house more than half of the world's population. This figure is predicted to expand by 2.5 billion people by 2050, with the majority of this expansion occurring in emerging nations.

In order to show that the UN sustainable development goals can only be achieved if the elements and processes of geodiversity are unquestionably taken into account in the global agenda, a review studied the geodiversity concept and draws connections with well-established concepts and strategies, specifically the ones related with natural capital and ecosystem services [76].

Cities have long been associated with riches, growth, and opportunity, but they are also experiencing unprecedented levels of inequality and poverty. Urbanization has an impact on natural resources and ecosystems, as well as climate change mitigation efforts, because cities rely heavily on fossil fuels for energy. Natural catastrophes pose a threat to cities. We have seen some of the biggest disasters caused by catastrophic weather occurrences during the last few decades. Cities they may be strengthened using an effective UR strategy to cut losses and enhance the effectiveness of the present asset systems.

2.3. Decision Science Support Mechanism and/or Tools

Decision science has applications in various fields of study and is recognized to provide supportive tools for different types of decision makers to make a concise and unbiased decision [77]. With regards to UR, there are few decision-making studies employing hard data in the post-disaster area, although this is critical to examine observable environmental aspects rather than depending simply on expert opinion. Employing only tacit knowledge is unproductive [78].

Disaster Risk Management (DRM) is a complex process that involves evaluating and mitigating the potential impacts of natural and man-made hazards on communities and infrastructure. Multicriteria Decision Making (MCDM) methods can be useful in DRM by helping decision makers to evaluate and compare alternative options for risk reduction and response [79,80].

Some of the most widely used MCDM [81] methods in DRM include (i) Analytic Hierarchy Process (AHP): AHP is a method that breaks down a complex decision problem into a hierarchy of smaller, more manageable sub-problems. It is particularly useful in DRM for evaluating and comparing alternative options for risk reduction and response, and for prioritizing response strategies; (ii) Multi-attribute Utility Theory (MAUT): MAUT is a method that allows the decision maker to assign numerical values to each criterion and then combine these values to form a single overall score for each alternative. It is useful in DRM for evaluating and comparing alternative options for risk reduction and response; (iii) Multi-Criteria Decision Analysis (MCDA): MCDA is a generic term that refers to a wide range of methods used to evaluate and compare alternatives based on multiple criteria. It includes methods such as AHP and MAUT, as well as other methods such as the Electre and Promethee methods [81–83].

In addition to these methods, GIS (Geographic Information System) is also widely used in DRM. GIS can provide spatial context to the data and can be used to display and analyze data in a spatial context, which can help decision makers to understand the problem and evaluate alternatives in a more comprehensive way. GIS can also be used to create hazard and vulnerability maps, which can be used to identify areas that are most at risk and to target risk reduction and response efforts. GIS can also be used to support decision-making by providing real-time information during an emergency response and can be used to analyze the effectiveness of response strategies after a disaster [84].

MCDM methods, such as AHP, MAUT and MCDA, are widely used in disaster risk management to evaluate and compare alternative options for risk reduction and response. GIS is also widely used in DRM as it can provide spatial context to the data and can be used to display and analyze data in a spatial context, support decision-making during an emergency response and can be used to analyze the effectiveness of response strategies after a disaster. With the integration of GIS and MCDM methods, decision makers can have a better understanding of the problem and can evaluate alternatives in a more comprehensive way.

The need, potential, and challenges for incorporating Life Cycle Assessment into traditional approaches to decision problems, as well as its application areas on transportation planning, flood management, and food production and consumption, are explored in a study that examines how environmental impacts are taken into account in various fields of interest for decision makers [85]. However, decision support systems alone are not sufficient. These can also benefit from various statistical analysis tools, such as bi-variate correlation, agglomerative hierarchical and non-hierarchical clustering (K-mean), principal component analysis, and multivariate regression models [86].

Urban resilience techniques may be implemented at various stages of the hazard chain, including disaster risk reduction, disaster preparation, and disaster response. Building UR strategies may strive to alleviate the consequences of catastrophes or avoid them from happening.

A significant aspect of asset or risk management systems is their decision-making function, by ensuring that activities are taken in a methodical and precise way and lead to intended results. The decision making role for classifying and assessing risks is the most essential aspect of risk management or the most significant control function in risk management, and is frequently emphasized in the discussion on risk management decisions [87].

The concept of asset management and how it can be integrated with risk management to improve decision making for urban resilience has been previously explored. There is an increasing awareness that asset management can be aligned with risk management strategies to improve decision making for UR [88].

The process of decision-making in asset management is a highly intricate undertaking that encompasses not only technical elements such as modeling and data analysis, but also human factors such as bias, uncertainty, and perception. In an era of Big Data, artificial intelligence, IoT, and machine learning, it is essential to recognize and factor in the effects of these human factors in order to make sound and effective decisions [89]. It is necessary to combine 'soft' and 'hard' issues in the decision-making process [90].

Ensuring that organizations adopt consistent approaches based on established best practices, rather than relying on disparate individual methods or a lack of auditable methods, poses a significant challenge. This is particularly true for the multitude of smaller decisions that can have a significant impact on asset management. Technical solutions that are highly advanced can often be difficult to comprehend and explain, resulting in the "black box" syndrome where the complexity of the model obscures the rationale behind the decision.

Risk-Informed Decision-Making (RIDM) is a methodology that provides a formalized, rational, and systematic approach to identifying, assessing, and communicating the various factors that support making a risk-informed decision [91,92]. Developed in collaboration between IREQ/Hydro-Quebec and the University of Quebec (UQTR), the RIDM process involves considering, appropriately weighting, and integrating a range of often complex inputs and insights into decision making [89,91].

In order to arrive at an appropriate decision, high-quality engineering analyses are necessary but not sufficient. It is crucial to adopt a comprehensive approach that integrates the outcomes of various quantitative analyses and other relevant, intangible and hardly quantifiable influence factors. Methods of Multi-Attribute Decision-Making (MADM) such as AHP, Fuzzy AHP, PROMETHE, TOPSIS, ELECTRE, and MAUT, can be considered to support the final decision-making. In this process, the decision maker, supported by subject matter experts, analysts, and stakeholders, must engage in a high-level analysis and deliberation, taking into account all relevant insights for a satisfactory decision-making [89].

The decision-making process in asset management is a multifaceted endeavor that necessitates a structured methodology for balancing various competing priorities, managing external and internal factors, and achieving a harmonious equilibrium between short-term needs and long-term benefits. Organizations can accomplish this by implementing a well-designed asset management system in accordance with the ISO 55000 family of standards [17,93]. However, organizations must also be prepared to address the risks and uncertainties associated with extreme and large-scale disruptive events in their strategic and asset management decisions. As such, it is crucial to integrate the concepts of resilience and asset management to achieve sustainable development, optimal service levels, and economic sustainability [94].

In the decision making process, it is imperative to strike a delicate balance between multiple competing interests and factors such as performance, risks, benefits, costs, opportunities, short-term goals, and long-term sustainability. Modern electrical utilities employ a variety of models and tools to mitigate uncertainties and better quantify risks within their asset management decision-making processes. However, it is essential to link the information and insights obtained from these quantitative models to the decision maker's needs and take into account other intangible factors that may have a significant impact on final decisions[92].

Geographic Information Systems (GIS), spatial data and maps are generally applied to better assess and control threats in the built environment. GIS has proven to be a useful tool for presenting and analyzing layers of information in a spatial manner since the 1990s. It offers decision makers with information that is simple to grasp and process. GIS-based decision-support systems promote communication between researchers and decision-makers and provide a platform for multidisciplinary research [95].

UR has been increasingly discussed and incorporated into policymaking in view of controlling hazards in cities/urban areas. Consequently, it became relevant to investigate methods for visualizing and mapping UR and to comprehend the added value deriving from these types of efforts. Previous research has shown that adaptive resilience is mapped after a disaster mostly through recovery measures, and that top-down techniques are commonly used to map inherent resilience. However, resilience maps do not examine the topic of resilience completely, resilience maps do not depict the ability of systems to adapt or evolve, nor do they reflect the systemic attribute of resilience [96].

This lends credence to the idea of strengthening urban resilience to ensure risk-aware spatial planning strategies for the built environment and key infrastructure, bringing a fresh perspective in the settings of socio-ecological reconstruction and the cultural vitality of civil society [29,97].

The relevance of assets and risk in the context of urban sustainability and resilience is emphasized in this section, where the management of assets and asset systems will be discussed in relation to our cities' infrastructure and buildings. To this extent, decision makers require a variety of tools and approaches to improve the decision making process in order to manage these asset systems that are vulnerable to diverse risks, such as tangible or intangible, natural, or man-made disasters. To arrive at a unified interdisciplinary solution for sustainable UR, a combination of data-driven and stochastic analysis will be needed. To that aim, this study attempted to identify the current trend in UR as well as potential research prospects that should be pursued in future research initiatives. These trends and gaps were retrieved via a rigorous process that included subjective and objective assessments to produce accurate and all-inclusive results.

3. Methodology

3.1. Rationale

This review article investigates the present state of UR research and implementation to constructed assets such as buildings and infrastructures. The authors performed a systematic literature review to ensure that the study results conform to a pre-defined and reproducible methodology and that the research quality is not impacted by a priori assumptions or the researcher's expertise, which is a typical feature of narrative literature reviews.

3.2. Protocol and Registration

The systematic literature review uses the Preferred Reporting Criteria for Systematic Reviews and Meta-Analyses format (PRISMA). PRISMA is a broadly accepted literature review process. It was established by a group of medical authors [98] to improve the clarity, dependability, and precision of systematic literature reviews. For more reliable reporting in a systematic review, these authors presented a 27 item checklist and a related flow diagram. Because of its transparency, reliability, and conciseness, the authors chose PRISMA to perform the systematic literature review of UR of buildings and infrastructures.

The identification step of the systematic study was followed by a paper screening, eligibility, and the final selection of the records to be included in the content analysis (Figure 2). The review process began with setting up the eligibility criteria, the information sources, and the search query. The first set of results was then filtered according to the eligibility criteria, the remaining articles are joined into a single set. Next, the papers were analyzed according to their title, abstract and keywords, and the papers out of scope were excluded. Finally, the texts of the remaining papers were fully read, and some additional and relevant references were included in this step. Again, the articles out of scope were removed and the final list of papers was obtained.

3.3. Eligibility Criteria

The evaluated papers in this study all meet three predefined qualifying criteria. First, because English has the most published and peer-reviewed papers, it was chosen as the publication language. The second criterion was to narrow down the keywords so that authors could gain insights on a specific focus of UR, namely infrastructure and building asset and risk management approaches supported with GIS-based decision tools.

Only peer-reviewed published records are considered to provide an additional level of quality assurance. There were no restrictions on the year of publication, the title of the journal or the number of citations.

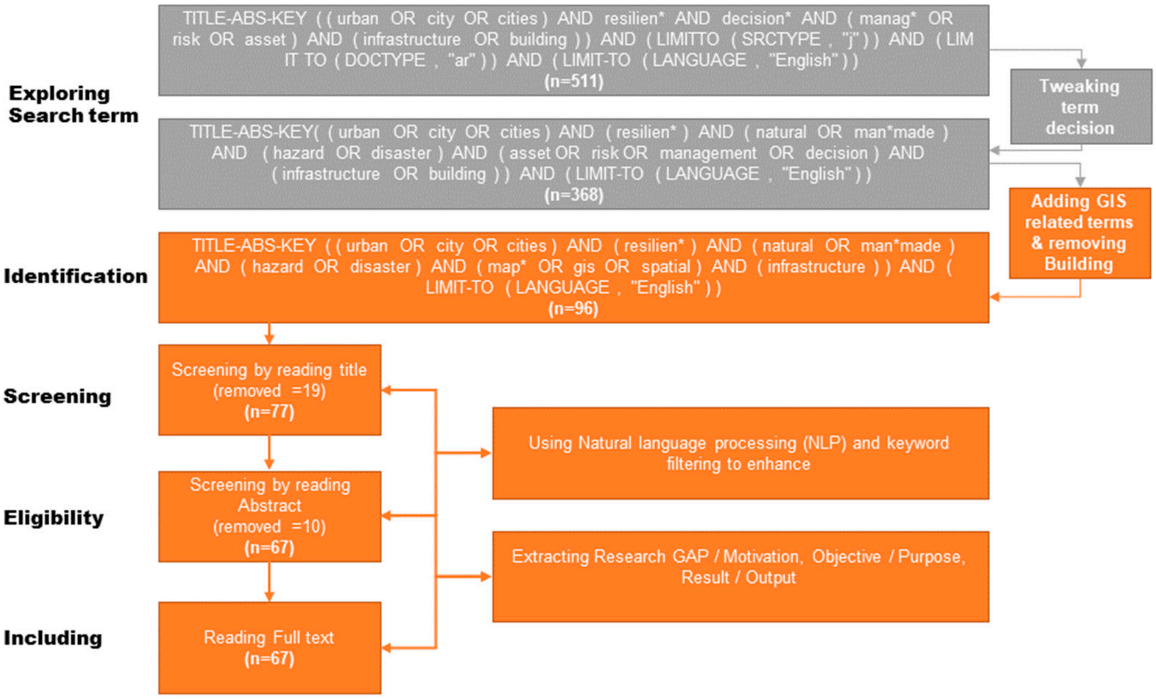

Figure 2. The PRISMA flow diagram (adapted from [98]).

3.4. Information Sources

The data for the bibliometric search, as well as the information sources used in the search, came from the Scopus database. The academic sector recognizes this database for its stringent quality requirements and absolute higher coverage in all fields including engineering than Web of Science [99], extensive article coverage, considerable citation, and abstract sources [100]. The Scopus search engine also employs a Boolean syntax, which enables the application of precise constraints and the generation of more refined results. Furthermore, this search engine enables a real-time bibliometric analysis of the results (distribution of publications by author, country, year, and so on), which adds value to the search and facilitates the iterative process of selecting an appropriate search phrase. The most recent search was conducted on 28 June 2022.

3.5. Search

Figure 2 shows the query structure and keywords utilized for this literature review. The authors cite the Scopus Search Guide for further information on this syntax [100]. Choosing the best structure and keywords for the search was an iterative process that began with a preliminary keyword search and was followed by a refining process based on the findings. The search string is divided into three sections: (1) the Urban Resilience (UR) domain; (2) the GIS and spatial analysis; (3) the various disasters infrastructures were subjected to.

3.6. Study Selection

The phrases used when searching the Scopus database, in view of the systematic literature review, are presented below. They was properly combined and crafted to cover the topic while applying adequate restrictions to avoid producing a large number of results. This is a crucial component of the systematic literature review study with impact on the final outcomes. Defining the search term, on the other hand, might make it clearer and more reproducible, which is an important aspect of a research article.

TITLE-ABS-KEY ((urban OR city OR cities) AND (map OR gis OR spatial) AND (resilien*) AND (natural OR manmade) AND (hazard OR disaster) AND (infrastructure)) AND (LIMIT-TO (LANGUAGE, “English”)).

The first part of the research string covers the study domain of asset and risk management. The second part covers Urban Resilience (UR) and is subdivided into two components. The first component is the primary keyword "urban" and possible synonyms, such as "cities" or "city" included in combination with the "OR" operator. The third part of the string covers the domain of resilience by using "resilien*" with the "AND" operator to cover potential variations. The next phrase in the search is "natural" OR "man*made" AND "hazard" OR "disaster," and their synonyms to encompass different types of disaster risks that are important to UR. This is to follow to next term subjecting to infrastructure and buildings. The fourth part includes "map*" OR "GIS" OR "spatial" to consider studies dealing with spatial analysis and visualization tools to enhance UR decision-making.

The authors opt to employ more search phrases while searching in all titles, abstracts, and keywords to limit down the quantity of results to make them more useable and to avoid having too many that make proper analysis hard. As a result of the initial search query, which contained 511 papers, it was then reduced to 96 scientific papers, 67 of which brought insights into the conclusion of this study.

3.7. Data Collection Process

The Scopus search engine records were exported to a spreadsheet and processed according to the PRISMA flow diagram with creating some extra columns on a spreadsheet to segregate and organize the articles based on their different characteristics (e.g., justification for exclusion, paper objectives, achievements, relevance, etc.). Each screened paper was downloaded and studied for the complete paper review step.

3.8. Risk of Bias

This study of the literature identified a few factors of bias risk. First, because there is no redundancy for dispute resolution, the reviewing process was handled by a single individual, which raises the possibility of compromising the overall quality of the study. The number of publications to be evaluated is another potential danger factor. Because of the large number of papers examined, the reviewer had to put in a lot of reading time throughout the screening process. This may cause reading fatigue and bias in the categorization of article relevance. To compensate for this situation, the reviewer set a daily limit of articles to screen.

Another possible source of bias is not including article restrictions. Choosing just journal articles for quality assurance was a trade-off that may have resulted in the removal of relevant and high-quality conference papers, which authors chose not to do.

One last example of a potential bias risk might be found in the publishing wording. Despite the fact that English is the most often used language in academia, certain publications were excluded owing to this limitation. Some of those publications, particularly those from countries where UR apps have a relevant degree of implementation, may give helpful information regarding the research issue (e.g., Germany and China).

4. Bibliometric Analysis Results

In comparison to prior UR reviews (e.g., [101–104], this review presents novelties as it offers a bibliometric assessment of the study trend using statistical analysis and Natural Language Processing (NLP) to extract the current trend of urban resilience using GIS-based decision-making tools. This systematic literature review is a direct result of the implementation of a systematic literature review (PRISMA), which allowed us to screen out articles that were out of scope and work mainly with those that were within the specified scope. Furthermore, the lack of research on the application of UR using GIS for cities facing natural disasters lessened the numbers throughout the screening phase (see flowchart in Figure 2), resulting in a bibliometric evaluation of just 67 papers. As a result, the various bibliometric analysis approaches (such as Natural Language Processing (NLP) keyword co-occurrence) gave inconsequential findings in this case, and the authors picked only those with relevant results to offer. The findings also revealed that there were no significant articles addressing UR research in collaboration with a GIS decision support system as a high-level system in the asset and risk management of cities.

4.1. Natural Language Processing of the Word Trend

In order to identify the key word trends in the 67 chosen articles, we used a natural language processing word cloud that is powered by artificial intelligence [105]. As shown in Table 1 and Figure 3, this method resulted in a word cloud and graph showing the phrases that appeared the most frequently when the titles, author keywords, and index keywords were combined. In the process of creating the illustrations, we eliminated some of the highly obvious terms that serve as the research's single keyword, such as "resilience", "urban", "disaster", "natural disasters", and specific names used to identify the countries under study. This has allowed us to develop a more related, interdisciplinary perspective on the subject.

Table 1. Keyword co-occurrence based on Monkey Learn.

Word	Count	Relevance
climate change	30	0.998
risk assessment	19	0.606
geographic information system	11	0.588
urban infrastructure	10	0.321
decision making	11	0.285
community resilience	8	0.285
disaster management	8	0.285
flood/flooding	74	0.285
baseline resilience indicators	5	0.267
flood risk management	5	0.267
green infrastructure	9	0.250
transportation infrastructure	8	0.250
land use	8	0.250
disaster resilience	14	0.214
infrastructural development	6	0.214
sustainable development	6	0.214
urban planning	6	0.214
risk management	13	0.178
critical infrastructure	8	0.178
infrastructure resilience	6	0.178
urban development	5	0.178
disaster prevention	5	0.178
disaster risk reduction	3	0.160
resilience knowledge system	3	0.160
electric network analysis	3	0.160
urban resilience knowledge	3	0.160
analytic hierarchy process	3	0.160
electric power network	3	0.160
principal components analysis	3	0.160
vulnerability	25	0.147
transportation system	5	0.143
spatial analysis	4	0.143
complex network	4	0.143
spatial planning	4	0.143

Figure 3. Word cloud of 67 chosen articles.

4.2. Annual Publications

In a recent period of five years, from 2017 to 2021, more than 75% of all selected papers (67) were published, according to a bibliometric analysis. The number of yearly publications has increased, particularly in 2021, and is expected to reach more than 15 publications in 2022 (Figure 4).

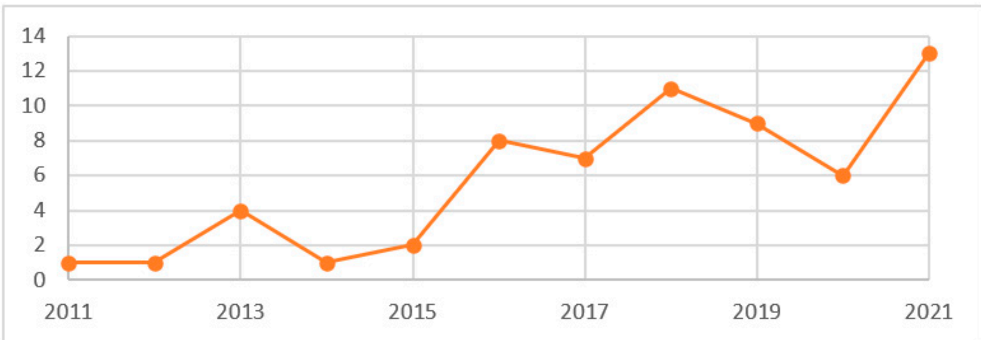

Figure 4. Annual publication from 2011 to 2021.

This development pattern fits the findings of previous UR-related reviews [96,102,106,107], corroborating the notion of UR as an important topic with expanding academic interest. The findings also revealed that there were no prominent publications in terms of UR research in combination with GIS decision support tools.

4.3. Subject Areas and Resource Type

The Scopus search engine's publication pattern of the 96 unscreened papers is indicated by topic area in Figure 5. To better emphasize the impact of each discipline area, authors choose to utilize percentages rather than numbers in this pie graphic. The second factor is that the articles are interdisciplinary, meaning that 96 of them span a total of 185 fields. The graph shows that 24, 19, and 17% (a total of 60 percent) of the results are related to environmental science, social science, and engineering fields, respectively. This suggest that all three of these disciplines contribute equally to UR, and any UR research projects should pay particular attention and integrate all three disciplines. The remaining 40 percent is generally distributed across earth and planetary sciences (12%), energy (5%), and computer science (4%), all of which are vital for use in upcoming research.

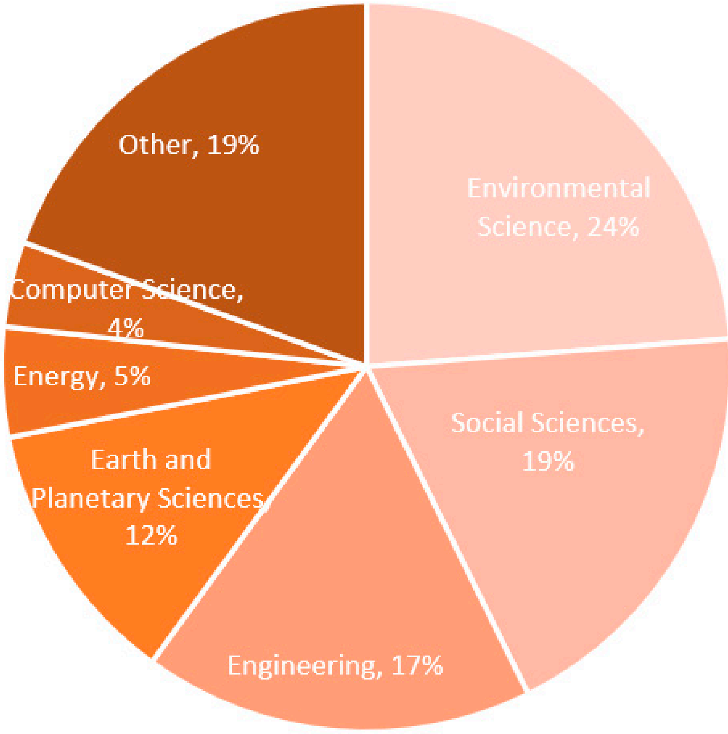

Figure 5. Research distribution along various disciplines.

Figure 6 illustrates the different types of papers, with articles accounting for 63% of the total, conference papers for 21%, and book chapters and reviews for 8% apiece. The majority of the papers are conceptual and analytical research that look for methods to structure UR and use such models and frameworks in real-world case studies. There are many different one-dimensional and multi-dimensional analyses of articles. For instance, the majority of them just examine floods, earthquakes, or other natural disasters as a single natural disaster, while some examine groups of them and how they interact.

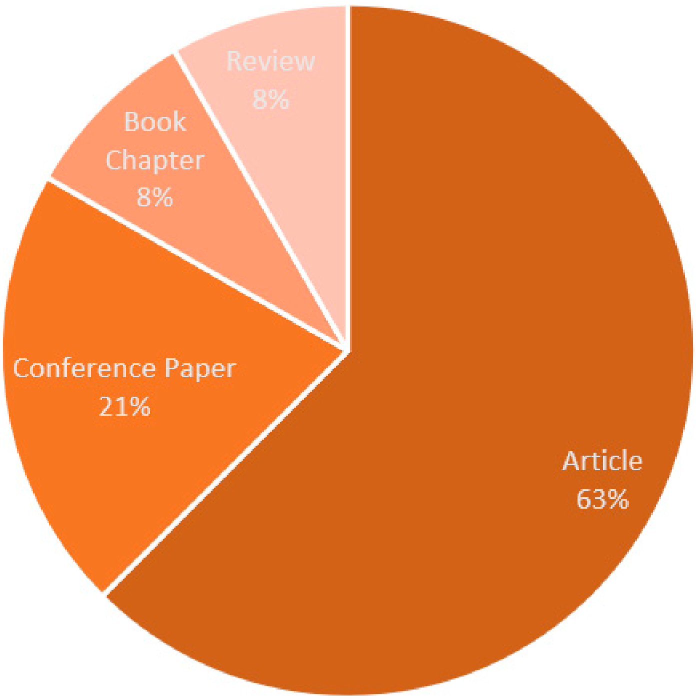

Figure 6. Paper type.

5. Discussion

This systematic literature review had two main objectives. The first objective was to highlight the major areas of discussion in UR publications. The second objective was to explore the knowledge gaps and future study opportunities for UR in decision science. The following sections discuss the extent to which these two objectives of the proposed systematic literature review are met. In Appendix A, a detailed bibliometric analysis is presented in the form of a table that includes the title, reference, research gap/motivation, objective/purpose, and result/output of all studies used.

5.1. Major Areas of Discussion in UR Publications

5.1.1. Climate Change

In terms of its effects on regional and temporal climatic variability and change rates, climate change is a long-term global change that neither happens by coincidence nor by design [33]. Urban climate change resilience acknowledges the complexities of rapidly expanding urban regions and the uncertainties related to climate change while embracing climate change adaptation, preventive activities, and disaster risk reduction [108].

The use of unsustainable resources, a shortage of housing and infrastructure, the prevalence of poverty, rapid urbanization, crime, natural disasters, and the effects of climate change are just a few of the problems that cities face. The concept of "excellent urban governance" is necessary for countries to successfully plan and implement sustainable development efforts [109]. Urban resilience is a holistic term that contributes to a city's capacity to manage unpredicted and foreseeable risk-related events in a sustainable manner. This has led researchers to investigate the significance of urban management governance and the link between strong urban governance and city resilience by document analysis.

For example, flood hazard modeling was developed as a methodology to help in assessing community resilience, because the Emergency Management Agency's Flood Insurance Rate Maps are insufficient for the changing requirements for public resilience evaluation and decision-making [110]. This methodology demonstrates the likely effects of climate change on civil infrastructure in the twenty-first century and argues that these effects are not insignificant but can be controlled with the appropriate engineering.

5.1.2. Disaster Risk Assessment and Treatment

The United Nations office for Disaster Risk Reduction (UNDRR) promotes the analysis of possible hazards and the assessment of current exposure and susceptibility circumstances that collectively potentially affect people, property, services, livelihoods, and the environment over which they rely. This can be done using qualitative or quantitative techniques [111]. Disaster risk assessments involve the following steps: (i) identifying hazards; reviewing technical aspects of hazards, such as their location, intensity, frequency, and probability; (ii) analyzing exposure and vulnerability, along with the physical, social, health, environmental, and economic dimensions; (iii) assessing the efficacy of existing and alternative coping mechanisms in light of likely risk scenarios.

UNDRR also discussed disaster risk management as the use of policies and techniques for reducing disaster risk in order to avoid new disaster risks, lower current disaster risks, and manage residual risks. This helps to increase disaster resilience and cut down on disaster losses [111]. It is possible to distinguish among prospective, corrective, and compensating disaster risk management—also known as residual risk management—actions in disaster risk management.

Many communities are vulnerable to natural disasters, resulting in economic, social, and environmental damages as a result of insufficient investment and planning. Cities must alter their institutional frameworks in order to foster a culture of Disaster Risk Reduction (DRR) and collect and distribute knowledge for sound decision-making [112]. Investing in early warning systems, developing risk assessments and vulnerability maps through financing for social services and infrastructure, and developing and enforcing land use policies to reduce hazards and regulate construction rules for safer human settlements are all important steps toward improving UR.

Risks and vulnerabilities are considered in urban planning, considering human habitation of hazard zones, hazard analysis and the creation of hazard maps, control over unauthorized development, scenario-based planning, the use of action and reaction characteristics, stakeholder engagement, proactive planning, level of flexibility, land, and appropriate acquisition [97,113].

The key results of the world energy council are that (1) for market tools, technology and data solutions, collaborations and partnerships, and communications, short-term agility is crucial; (2) lack of coordination, complicated backup plans, underused communication, and escalating failure costs are major obstacles to the dynamic resilience of whole energy systems in transition. The primary facilitators of dynamic resilience are improved climate change scenario modeling and weather forecasts in determining long-term adaptation needs; (3) Building resilience across more intricate and embedded energy systems requires a larger role for simulated and shared experiences, participatory preparation planning, and other best-practice learning methods [66].

5.1.3. Geographic Information System (GIS)

The growing availability of 'big data' has prompted hopes that the world can be more predictable and controllable. Real-time management has the potential to overcome instabilities induced by delayed input or a lack of knowledge. However, there are significant limitations to this: having too much data might make it impossible to distinguish between accurate and ambiguous or wrong information, resulting in poor decision-making. Having too much information may result in a more obscure rather than a more truthful image [56].

GIS is a digital ability to collect, store, verify, and display data about locations on the land surface [114]. GIS can offer more accurate and meaningful information about the UR indicators of cities to urban policy makers and high-level decision maker [115]. It is possible to transform raw data into a more tangible and understandable tool that researchers and practitioners can use more frequently while spending less time digesting and generating new insights in this broad field of study by analyzing and visualizing UR dimensions, indicators, and parameters.

Multi-hazard spatial and geographical scales analysis is essential for improving resilience and disaster response in rural towns and cities vulnerable to severe seasonal weather [116].

Based on a cooperative geographical resilience assessment technique that includes three resilience evaluation methods and the use of geo-visualization techniques, including the use of GIS for data processing, assessment, visualization, mapping, and model processing, spatial decision-support tools can be developed. This approach integrates the territory's technical, urban, and social components while emphasizing the multiple alternatives available to promote regional resilience through collaboration and the use of a visual tool [117]. There are various services such as Google Maps, Google Earth, and free and/or open-source tools such as QGIS (Quantum GIS), GRASS, SAGA, Monteverdi, Sextante GIS, and Orfeo Toolbox, which can help to develop multiple GIS-based models [118].

5.1.4. Urban and Transportation Infrastructure

A coordinated infrastructure resilience evaluation and planning process should consider infrastructure interconnection and the impacts of cascading failures. Socioeconomic aspects and land use characteristics should be incorporated in the interdependent resilience assessment for a more full and equitable resilience planning process [119]. Findings in this area also emphasized the importance of having a strong and developed economy, excellent education, and training programs to raise public awareness of disaster prevention and mitigation, adequate funding for vital infrastructure, particularly in the areas of transportation and communication, sound environmental policies to safeguard ecosystems and water resources, and extra care and budgets for disaster risk for vulnerable groups [120].

It is necessary to analyze how the availability and distribution of transportation infrastructure might affect the disaster resilience of human-infrastructure systems in metropolitan settings since disaster resilience is viewed as a dynamic process before, during, and after catastrophes in different communities. For example, areas with more transportation diversity show greater resilience in terms of their mobility both during and after the storm [121].

5.1.5. Decision Making and Disaster Management

It can be argued that some important safety procedures against man-made disasters are not performed today due to a lack of theoretical knowledge and, as a result, incorrect policy actions. Some authors advocate that there a common misunderstanding about complex systems is to consider that these can be adequately governed or that socioeconomic systems self-correct without significant threats to society. Due to the systemic character of man-made catastrophes, it is difficult to make someone accountable for the harm inflicted. As a result, traditional self-adjustment and feedback processes fail to assure responsible behavior to prevent potential tragedies [56]. Because the world's interconnect assets and risk management strategies are too complicated to be optimized by top-down management in real time, the notion of a sole dictator would not work efficiently. Decentralized cooperation with impacted system components can produce better results that are tailored to local requirements. This implies that a participative strategy that makes use of local resources might be more effective. This method is also more resilient to disruptions.

The Sendai Framework for Disaster Risk Reduction applies to the risk of small-scale and large-scale, frequent, and rare, unexpected and gradual disasters caused by natural or manmade disasters, and environment related, technological, and biological associated risks, with the goal of significantly reducing disaster risk and risks in lives, livelihoods, and health, and economic, physical, social, cultural, and environmental assets of individuals, organizations, societies, and governments [72]. It aims to "prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience".

There are various frameworks that can be support decision making and enhance UR, namely, action plans for future vigilance to lessen the increasing effects of risks on cities. These have been devised as a road map for establishing an UR knowledge system for practitioners, decision-makers, and local authorities [122].

UR decision-making tools are built in response to the needs of the urban environment, considering many dimensions and indicators, functioning alone or in conjunction, both with and without weighting of MCDM approaches, and can be subjective (expert-based) or objective (data-driven/stochastic). Choosing the appropriate mix of techniques is context-dependent and is a challenge in itself. This is something that needs further exploration and future research work.

5.1.6. Community and Disaster Resilience

Many communities are vulnerable to natural disasters, resulting in economic, social, and environmental damages [112]. Due to the loss of lives and livelihoods caused by flood dangers, the government began to think about the need for research aimed at reducing flood impacts and raising awareness to build more adaptable and resilient communities [123].

There are various tools such as the Baseline Resilience Indicators for Community (BRIC), which examines the baseline resilience to natural hazards [124]. A study finding also highlighted the value of having a robust and developed economy, excellent education, and training programs to increase public awareness of disaster prevention and mitigation, adequate funding for crucial infrastructure, particularly in the areas of transportation and communication, sound environmental policies to safeguard ecosystems and water resources, and extra care and budgets for disaster risk for vulnerable groups [120].

5.1.7. Green Infrastructure and Sustainable Development

Actions that work with and improve natural environments are examples of nature-based solutions [125]. There are several instances of nature-based approaches. Soil erosion and flood danger can be reduced by afforestation, reforestation, and the preservation of current forestland. Recovering marshlands and natural wetlands helps coastal communities protect themselves against severe storms [126]. The urban heat island impact is decreased by creating green space in neighborhoods. Such nature-based solutions have various co-benefits in addition to protecting communities from the worst impacts of extreme weather [127].

Neighborhood parks and street trees boosted the advantages in residential areas. Paddy fields have also been proven to be particularly efficient in reducing local climate, which is especially relevant where agricultural grounds border residential areas [128]. It also was discovered that green infrastructure needs a thorough grasp of the political, social, economic, and environmental elements of the poor urban population [129]. The key is cohesive collaboration and full engagement of urban stakeholders [130].

5.2. Knowledge Gaps and Future Study Opportunities on UR and Decision Science

5.2.1. Resilience Definition and Multidisciplinary Analysis

Resilience is often characterized as a system's capacity to resist a substantial shock and sustain or promptly continue at normal performance in UR literature. However, there is dispute over both the traits that define resilience and the proper analytical unit for resilience assessment. Because of the many intellectual traditions and lineages represented in the various study fields, there is heterogeneity in how the term of resilience is used [131]. As a result, the context in which it is used may define urban resilience as anything from the capability of the system to adjust to changing environmental conditions to the degree of endurance to maintain functional performance and the ability to sprint back.

5.2.2. Unified Scalable and Adoptable UR Model

Predictions appear conceivable over the short-term and in a probabilistic perspective for today's build environment. Even with all the facts in the world, one cannot predict the future; nonetheless, one can establish if systems are prone to cascades or not. Furthermore, faulty system components can be leveraged to provide early warning signals. However, if safety procedures are not taken, spontaneous cascades may become uncontrollable and devastating. To put it another way, predictability and controllability are a result of effective system operation and design. Learning how to put this into effective approaches and how to exploit the good aspects of cascade effects will be a twenty-first-century problem [56].

There are certain multi-dimensional UR models and frameworks that operate rather well in their intended applications, but by considering the particular needs of different cities and catastrophes, these models must be rebuilt each time by researchers. To that end, a more advanced model that is scalable and adaptive for different disasters and cities based on their demands and priorities is required.

5.2.3. Geographic Information System (GIS) UR Multidimensional Tools

There is a requirement to transform all data into geo-tagged transferrable data to enable breaking their information into statistical models and making evaluation by decision support systems possible, in order for high level decision makers to better understand the problem and solution. To improve the model, the GIS-based model should be worked alongside raw data in a cloud-based environment.

5.2.4. Stochastic Analysis of Virtual Cities

Because data acquisition is costly and time demanding, extending the acquired data to a broader ecosystem would be extremely valuable. To that aim, if the acquired data do not cover all characteristics of the concept, they can be expanded using inverse distribution employing local or global reverse sampling methods for continuous data and discrete variables dependent on their application. Then, to establish a larger prospective and save survey time and expense, expand this amplified data to all available locations in the city. This solution may not be the most accurate and may be biased in certain circumstances, but it may be used as a tool in research to provide preliminary insight into how to enhance indicators before making final decisions on final dimensions and indicators.

5.2.5. Scenario-Based Decision Making Mechanism for UR

Cities require a completely novel comprehensive and inclusive framework for recognizing and adopting disruptions, integrating multiple objectives and goals, and proactively preparing towards enhanced urban futures in policy and planning [58,132].

6. Conclusions

Natural and man-made disasters caused by climate change, natural disasters, and technology advancement can cause major disruptions and damage to built environment components, which are crucial for functioning modern society. Because of direct exposure to several climatic risks such as high temperature and precipitation, and sea-level rises, the built environment is more exposed to climate change consequences than ever before. As a result, implementing UR measures into the built environment is critical for asset systems to endure significantly and avoid failure or breakdown, and adapt quickly as a result of various mentioned disruptions. Efficient decision making in the UR domain enables public and private authorities to evolve into resilient spots capable of withstanding and adapting to disruptions. This is accomplished by utilizing the concept of fuzzy bounded and unbounded rationality, where the decision-maker may choose the best course of action based on the facts at hand.

This paper presents a systematic literature review of the past studies conducted on the UR and decision science perspective. The systematic literature review is organized under five main headings: The first section of this article examines background information and adjacent disciplines that can have a favorable influence on the subject of UR. The second section goes about the technique (PRISMA) and how it was employed in this study. The third section goes through bibliometrics and results analysis, while the fourth section goes over the study's findings and supports both objectives. The conclusion and discussion of future research constitute the study's last component.

Objective one was to highlight the major areas of discussion in UR publications: (1) climate change; (2) disaster risk assessments and management; (3) geographic information system; (4) urban and transportation infrastructure; (5) decision making and disaster management; (6) community and disaster resilience; (7) green infrastructure and sustainable development.

For the second objective, the main research gaps are identified as (1) resilience definition and multidisciplinary analysis; (2) unified scalable and adoptable UR model; (3) geographic information system (GIS) UR multidimensional tools; (4) stochastic analysis of virtual cities; (5) scenario-based decision-making mechanism for UR. All of these identified aspects can be significantly improved for further analysis of the UR and disaster risks, and the authors will try to resolve these gaps in their future research.

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Institutional Review Board Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Research GAP/Motivation, Objective/Purpose, Result/Output of reviewed papers.

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Network-based Assessment of Metro Infrastructure with a Spatial–temporal Resilience Cycle Framework	[133]	The topology of the network was emphasized in current network-based resilience assessment methods, but the effects of flow pattern temporal fluctuation and system geographic distribution, which offer unique human-centered insights into resilience, were seldom considered.	utilized a framework for resilience that consists of the four life-cycle stages that are connected with disruptive events: readiness, robustness, recoverability, and adaptability. The system and user resilience are captured by the suggested flow-weighted and geographical analysis.	The network's resilience to random failures is strongly impacted negatively by the average flow trip distance. The node homogeneity that arises from the readiness stage may also be used to explain why the network is susceptible to random failures. If the shared dangers for the neighboring stations are kept to a minimum, densely constructed metro stations are shown to be particularly beneficial during the recovery period. For all relevant stakeholders, the resilience cycle framework offers insights that may be put to use.
Multidimensional hazards, vulnerabilities, and perceived risks regarding climate change and COVID-19 at the city level: An empirical study from Haifa, Israel	[134]	multidimensional hazards, vulnerabilities, and resilience	studied Haifa, a socially diverse Coastal city, for its many risks, vulnerabilities, and resilience. By utilizing land use, welfare, and digital elevation model data, geographic information systems geoprocessing algorithms created spatial metrics of heatwaves, flooding, wildfires, and social fragility. Residents were given access to an online survey measuring perceived risk, sensation of danger, and community resilience.	The city's many climatic vulnerabilities and hazards reflect its physical and socioeconomic features: lower sections are more vulnerable to heat and floods, while higher districts are more vulnerable to wildfires. All geographic areas and demographic groups face some risk, but the distribution of climatic risks and vulnerabilities is uneven and varied, with some areas of the country being more vulnerable than others. Although the downtown neighborhood has more social vulnerabilities than uptown, where wildfires are the major threat and aging is the main risk, its people are perceived as being more resilient. Implications for urban climate policy: By investing in appropriate infrastructure and promoting community resilience, local stresses should be reduced at the neighborhood level.
Predictive resilience of interdependent water and transportation infrastructures: A sociotechnical approach	[119]	considered physical, spatial, and social dimensions simultaneously	an approach for evaluating resilience for interconnected water and transportation systems. The approach includes a sociotechnical resilience evaluation that considers the physical network of these facilities, social vulnerability indicators, and predictive analytics. It allows us to gauge the effects of arbitrary failures brought on by deteriorating infrastructure, natural calamities, and the cascade failures they cause.	A coordinated infrastructure resilience evaluation and planning process should include the interdependence of the infrastructure as well as the effects of cascade failures. For a more thorough and fair resilience planning process, socioeconomic elements and land use characteristics should also be included in the interdependent resilience assessment.
Assessment of NBS Impact on Pluvial Flood Regulation Within Urban Areas: A Case Study in Coimbra, Portugal	[135]	To deal with the rising flood risk brought on by urbanization and climate change, nature-based solutions (NBS) deployment may be essential. lack of research Assessing the effects of NBS	evaluates the effects of a Green Infrastructure (GI) that serves as an NBS for runoff control and flood hazard reduction in Coimbra, Portugal.	Nature-Based Solutions (NBS) adopted can absorb runoff produced by a 20 year storm, lowering the flood peak and danger in downstream metropolitan areas. This efficiency is reached by integrating blue, green, and grey components, and it has proven effective in improving urban resilience. The NBS's green and blue aspects provide additional ecosystem services, including as environmental, social, and economic advantages (co-benefits), which are important for human well-being in metropolitan environments.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Resiliency assessment of road networks during mega sport events: The case of FIFA world cup Qatar 2022	[136]	High density concentrates the workload on host cities' infrastructures, which must maintain a reasonable degree of operation despite any potential disruption;	a multidimensional evaluation method that emphasizes the performance of essential trips and network cohesiveness under a variety of disruption scenarios, such as incidents, deliberate attacks, and natural disasters. Given that Doha will serve as the host city for the FIFA World Cup in Qatar in 2022 and because it demonstrated a high level of resilience against purposeful threats and event scenarios, the framework was applied to the Doha Road network.	The network suffered from substantial fragmentation during the flooding natural hazard scenario, indicating low resilience and emphasizing the need for better storm management strategies. Future studies might look into ways to improve accuracy by using weighted graphs or by including other assessment methods into the framework.
Building resilience to natural hazards at a local level in Germany—research note on dealing with tensions at the interface of science and practice	[137]	Building resilience is defined by conflicts and the integration of a variety of techniques to cope with disturbances.	Implements a strategic spatial planning viewpoint and introduces the organizational and management study concept of "motors of change" to emphasize three ways to coping with tensions disruption: building a strategic focus of knowledge integration, defining priorities to increase resilience as a pro-active capacity of Disaster Risk Reduction (DRR), and compromise in the trade-offs management, including those among resilience dimensions.	Building resilience at the local level in Germany, coping with heat stress in urban areas, reducing the danger of major flood occurrences, and studying the resilience of new infrastructure solutions are all evident.
Governance of urban green infrastructure in informal settlements of windhoek, Namibia	[138]	Current governance institutions are frequently inadequately equipped to provide the level of design–build. The incorporation of UGI into municipal objectives, spatial planning, and specialized planning processes is restricted.	Using Windhoek, Namibia as a case study, we investigated established regulatory concept by using individual interviews, focus groups, and participating member survey results.	Five green infrastructure initiatives were used to deconstruct governance complexities, and different prospects for effective cooperation efforts that leverage creative governance methods were discovered. Namibia's urgent need for climate resilience provides a policy and practice opportunity for adopting context-specific approaches to multidimensional level.
An evaluation of urban resilience to flooding	[139]	The capacity to measure a city's resilience to floods is critical since it would serve to enhance resilience while also directing planning and development.	To evaluate and analyze the specified evaluation indicators, an interpretative structure and network analysis technique (ISM-ANP) model is utilized.	Which indicator is more significant in which city
Effective environment indicators on improving the resilience of Mashhad neighborhood	[140]	Resilience is a multifaceted and complicated term, and any attempt to assess it must consider its social, economic, physical, and environmental elements.	Assess the ability of urban resilience by providing numerous indicators that enhance resilience. This research is divided into two parts: resilience dimensions and resilience criteria. To quantify resilience capability, this study combined three domains of resilience: social, cultural, physical, environmental, and economic, with four characteristics of a resilient city: resistance, adaptive capacity, redundancy, and recovery.	In chosen areas, urban resilience is significantly linked to social variables such as citizens' knowledge and awareness, the level of public involvement, economic indicators such as income and employment, and physical–environmental status in terms of urban and health infrastructure.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
How to tackle complexity in urban climate resilience? Negotiating climate science, adaptation, and multi-level governance in India	[141]	The complexity and considerable ambiguity make it difficult to establish urban resilience metrics in a methodical way. The complexity results from the interaction of several unique factors in climate sciences (method, priority, level of intervention), urban governance (precipitation and temperature anomalies at various sites, RCPs, timeframe), and adaptation solutions (functional mandate, institutional capacity, and plans or policies).	In order to locate, ground, and operationalize resilience in cities, research looks at how divergent and complex knowledge and information in various inter-disciplines may be integrated for systematic "negotiation." Suggests incorporating appropriate adaptation strategies for the following five important urban sectors: water, infrastructure (including energy), construction, urban planning, and health.	A set of climate resilience-building initiatives for policy implementation through national/state policies, municipal urban planning, and the creation of city resilience strategies, as well as an advancement in the study of "negotiated resilience" in urban areas.
The next big earthquake may inflict a multi-hazard crisis–Insights from COVID-19, extreme weather, and resilience in peripheral cities of Israel	[116]	Remote areas of the world may find it difficult to deal with an earthquake's aftermath while also dealing with an epidemic or severe weather that may be occurring at the same time.	Specifically note the impact of overlapping catastrophes and seasonal pressures. It is anticipated that the sporadic visitor population in these outlying cities would strain local emergency services. To illustrate how seasonal tourist and weather conditions exacerbate the suffering and danger in a multi-hazard environment, a seasonal over burden parameter is proposed.	Shows the necessity of multi-hazard temporal and spatial scales analysis for enhancing resilience and emergency planning in outlying cities and towns exposed to severe seasonal weather.
Rethinking disaster resilience in high-density cities: Towards an urban resilience knowledge system	[122]	Considering crowded built environment, high-density cities (HDCs) must promote greater disasters resilience assessments.	It provides an example of an HDC-specific spatial disaster resilience profiling methodology. The indicator set is utilized to determine the spatially varying patterns of neighborhood catastrophe resilience. It is offered for resilience evaluation. A spatially relative catastrophe resilience index is created using building-level data for 24 indicators and infrastructure data. The Analysis of Variance technique is used to examine the distribution of resilience in order to provide planners with information on discrepancies between various resilience components. Multiple geo-information models are used in the spatial evaluations to determine the regions of importance for intervention.	It offers a road map for developing an urban resilience knowledge system, enabling practitioners, decision-makers, and local authorities to create action plans for future vigilance decreasing the deteriorating consequences of hazards on cities.
Memorial parking trees: Resilient modular design with nature-based solutions in vulnerable urban areas	[142]	The application of GIS mapping and technique can aid in create a safer environment region.	It used the following three indicators to underpin risk evaluations for London, Rio de Janeiro, and Los Angeles: extreme temperature, quality of air, and flood-prone locations.	The indicators that would enable to select these regions for a faster and more effective decision-making strategy are income and the neighborhood's accessibility to healthcare.
Operationalizing urban resilience to floods in island territories—application in Punaauia, French Polynesia	[117]	Small Island Developing States are more susceptible to natural disasters due to climate change and growing population. The idea of spatial resilience offers potential as a solution to urban flood challenges in response to urbanization in vulnerable regions.	The goal is to create a spatial decision-support tool based on a cooperative geographical resilience assessment technique. The proposed approach includes three resilience evaluation methods and use of revisualization techniques, including the use of GIS for data processing, assessment, visualization, mapping, and model processing. Through collaborating and the use of a visual tool, this technique combines the territory's technical, urban, and social components while highlighting the numerous mechanisms available to increase regional resilience.	The outcomes show that these techniques for evaluating resilience may be reproduced. They emphasize the possibility of a cooperative strategy to identify crucial infrastructures and produce prospective decision support to enhance the territory's capacity to function in spite of a disruption and to rebuild after this interruption.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Natural Hazards and Landslide Risk Management in Ukraine	[143]	Landslides are frequent natural hazards in Ukraine. They are frequently brought on by certain geological features, rainfall, and human activity. The increase in human activity on landslide-prone slopes is the primary cause of the growth in the number of landslides.	It deals with resilience, sustainable cities and communities, short-term environmental shock response, and long-term environmental change. Evaluation of landslide threats and management of landslide risk rely on two primary methods. The first method is based on mapping, geographic information systems (GIS), remote sensing data, and statistical analysis of geo-environmental factors associated with the incidence of landslides. The second method describes the on-the-ground monitoring, modeling, and landslide activity for the regional forecasts.	It serves as a foundation for the secure and efficient operation of infrastructure facilities, the reduction of socioeconomic and financial risks, and the development of effective prevention and mitigation measures. It introduces the relevant data to assist educate policy choices about the relative importance of hazards in terms of preserving lives and safeguarding livelihoods in Ukraine.
Assessment of Urban Infrastructures Exposed to Flood Using Susceptibility Map and Google Earth Engine	[144]	Extreme hydrological natural disasters, like floods, not only endanger life and property but also seriously harm vital facilities that must continue to function even in difficult circumstances. Therefore, it is important to identify flood-prone locations in order to comprehend how important infrastructure is susceptible to catastrophic floods.	By use of Sentinel 3 satellite pictures in Google Earth Engine, flood-prone regions and their vulnerability are mapped using machine learning approaches such as boosted regression tree (BRT) and generalized linear model (GLM).	In Shiraz District, the capital of Fars Province, the assessment of flood risk on critical infrastructures, including hospitals, pharmacies, banks, fire stations, automated teller machines, fuel stations, speed cameras, and mosques, revealed that these buildings were at high and very high risk of flooding. The study of the flood risk on the nine most populous cities in Fars Province was also conducted, and the results showed that Shiraz had the highest proportion of schools at extremely elevated risk (92.98%).
Assessing the Impact of Transportation Diversity on Post disaster Intraurban Mobility	[145]	Diversity is considered as a crucial component of transportation infrastructure resilience, although there is little empirical research connecting the two.	The effect of transportation variety on mobility in New York City during Hurricane Sandy is studied in this work. A recently developed method using GIS data from the transportation system measures transportation variety, which is the availability and distribution of modes in a community.	The findings demonstrate that transportation variety affects individual post-disaster mobility and reveal an empirical relationship between transportation diversity and intraurban mobility following natural disasters such as Hurricane Sandy. The findings further expand our understanding of the fundamental causes of changes in human mobility after catastrophic events, which adds to the mobility resilience literature. The selected strategy also encourages identifying regions with minimal transportation variety, which might allow for more specialized management of infrastructure and urban resilience.
Mapping resilience of Houston freeway network during Hurricane Harvey using extreme travel time metrics	[146]	Assessing how traffic behaved during such disasters, including changes in volume and speed, might help determine how resilient the road system is. Additionally, determining which road linkages and corridors are most impacted by natural disasters and determining the impact on traffic are essential elements in developing traffic management measures for reducing potential dangers. The absence of data on the state of the roads and traffic after natural disasters is a major obstacle to achieving the aforementioned goals.	By examining the features of extreme journey time data, a different approach to recognizing the traffic fluctuations brought on by a natural disaster (Hurricane Harvey) over an urban traffic network is described that uses algorithms for anomaly identification and time series decomposition to examine the geographical impacts of the hurricane on the traffic conditions.	It suggests that by accounting for both the initial damage and recovery, the measures created are efficient in estimating the resilience of traffic networks against natural disasters.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
A GIS approach to analysing the spatial pattern of baseline resilience indicators for community (BRIC)	[124]	Baseline Resilience Indicators for Community (BRIC) in northeaster Taiwan	Through the Baseline Resilience Indicators for Community (BRIC) in northeaster Taiwan, it examines the baseline resilience to natural hazards that somewhat adjusted the BRIC based on the unique circumstances of our research location. Because of the connection between some of the subcomponents, this problem is solved using Principal Component Analysis (PCA). As a result, it slightly altered the subcomponent categorization and combined socioeconomic community resilience with social resilience and community capital resilience. The outcome of Geographically Weighted Regression (GWR) demonstrates that the BRIC that was constructed is still valid, despite the fact that indicators changed.	The urban neighborhood in plain regions is the group of high resilience locations, according to spatial autocorrelation study. On the other hand, a substantial portion of the mountainous regions constitutes a group of low resilience zones. The most significant element influencing this distribution is terrain. Plain locations have advantageous traits that can spur growth and produce highly socioeconomic resilient communities. On the other hand, mountainous places lack these benefits.
Benchmarking Community Disaster Resilience in Nepal	[147]	Nepal offers a special opportunity for examining disaster resilience in the context of the developing world because of its vulnerability to a variety of risks and its recent experience with a significant earthquake in 2015. There has not yet been research that looks at community resilience to disaster throughout the whole nation of Nepal.	This study uses mostly census data to quantify disaster resilience at the village level in Nepal. A total of 22 variables were chosen as indicators of social, economic, community, infrastructural, and environmental resilience under the Disaster Resilience of Place (DROP) model. Using a main component analysis, community resilience was evaluated for 3971 municipalities and Village Development Communities (VDCs). A cluster analysis was also conducted to identify resilient geographical patterns.	Analyses show that there are regional differences in community catastrophe resilience. The western and far western Hill regions, as well as the capital city of Kathmandu, have very robust communities. However, compared to the rest of the country, the whole Tarai area, which is home to the majority of Nepal's people, has just moderate levels of resilience. The findings of this research give empirical information that might enable decision-makers in allocating financial resources to boost local resilience.
Mapping of green infrastructure in Sakura City, central Japan focusing on local climate mitigation	[128]	Interrelated systems of green areas can help to preserve the values and functions of natural ecosystems while also delivering numerous advantages to human populations, such as increased resilience. As a result, Green Infrastructure is a fundamental ecological framework required for environmental, social, and economic sustainability. Green infrastructures, on the other hand, vary greatly from area to region, making precise maps of data vital for enabling spatial planning, such as risk reduction measures and habitat evaluations.	This research aims to produce a municipal-scale green infrastructure map, which is the fundamental level of geographic planning and administration.	The study indicate that the advantages of climate mitigation were greatest in the area surrounding Lake Infauna, as well as in dense forests. Neighborhood parks and street trees boosted the advantages in residential areas. Paddy fields have also been proven to be particularly efficient in reducing local climate, which is especially relevant in agricultural grounds border residential areas.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Evolving concept of resilience: soft measures of flood risk management in Japan	[148]	The idea of resilience is changing to reflect changes in climate, socioeconomics, technology, and so on. Throughout its history, Japan has dealt with natural calamities and succeeded in limiting flood damage. For the previous half-century, the government has invested in flood protection infrastructure at a rate of one percent of national income, allowing it to safeguard large cities against floods caused by major rivers. While big rivers are effectively protected, danger regions near small rivers and hill areas remain vulnerable to floods. Since the 2000s, the nation has expanded soft measures to protect people's lives, such as danger mapping, early warning, and evacuation promotion.	This article examines aspects impacting resilience by evaluating flood risk management policy changes, particularly soft measures, in Japan. The paper investigates the changing processes of soft measures by evaluating the amendment of flood control legislation.	It was discovered that the idea of resilience in soft measures is developing in response to many developments, such as budgetary constraints, decreased infrastructure investment, an aging population, urbanization, technological advancement, and climate change. Based on lessons learned from the expanding idea of resilience, the author suggests that developing nations create soft measures that consider numerous changes in socioeconomic and ecological situations, as well as invest in infrastructure.
Citizen-centric driven approach on disaster resilience priority needs through text mining	[149]	Natural disasters such as floods, earthquakes, and volcanic eruptions are common in the Philippines. Legazpi City is now investing in disaster resilience as its top priority program of action, among others.	The study included stratified random sampling, Key Informant Interviews (KII), and Topic Modeling using Latent Dirichlet Algorithm (LDA), resulting in 649 unique instances that were chosen for thematic analysis from 662 data sets after filtering and cleaning.	The findings of text mining revealed that the majority of vulnerable groups, including youth, regardless of hazard type, recommended that in case of disaster, emergency items such as canned goods, water, cell phone, portable radio, first aid kit, flashlight, medicines, hygiene kit, important documents, slippers, extra clothing, match and lighter, and money should be in their get-go bags.
Adaptation as an indicator of measuring low-impact-development effectiveness in urban flooding risk mitigation	[150]	To augment traditional drainage facilities, frequent and intense urban flooding necessitates widespread use of low-impact development (LID).	It characterizes the resilient infrastructure framework with a focus on adaptation, which is the ability of a social-ecological system to react to varied natural hazards and absorb negative consequences. We contend that adaptation is a measure of LID success.	However, spatial inequality and accumulation of various levels of adaptation are evident. This outcome is due to a relatively low absorption capacity because most areas will have a relatively high recovery capacity but retain a low absorption capacity with the construction of LID projects. A relatively mild increase in absorption capacity is due to the quality of man-made infrastructural development conflicting across different areas of Gongming; for example, some infrastructures are constructed by the government, whereas others by developers and villagers. In addition, the topographical factor makes some areas in Gongming lower lying than others and is therefore increasingly vulnerable to urban flooding during rainstorms given the difficulty of discharging the surface runoff, thereby limiting the effectiveness of LID projects. Furthermore, the spatial inequality of adaptation improvement where LID projects cannot be evenly distributed within the research area leads to the unequal distribution of adaptation. These findings can confirm that the government can practically use adaptation as an indicator in evaluating LID effectiveness and identifying the problematic stages of drainage resilience in urban flooding risk mitigation.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Good urban governance and city resilience: An afrocentric approach to sustainable development	[109]	Cities suffer a variety of adversities and concerns, including unsustainable resource usage, a lack of housing and infrastructure, the predominance of poverty, fast urbanization, crime, catastrophes, and the consequences of climate change. City resilience is an integrative term that contributes to a city's ability to manage unexpected and foreseeable risk-related occurrences in a sustainable manner.	It seeks to investigate the significance of urban management governance in Africa, as well as the link between strong urban governance and city resilience by document analysis.	African nations have had some triumphs, but there are still numerous obstacles in terms of "good" and "sustainable" urban government. According to the findings, the concept of "excellent urban governance" is required for African countries to successfully plan and implement sustainable development efforts.
Are Arab cities prepared to face disaster risks? Challenges and opportunities	[112]	Many Arab communities are vulnerable to natural disasters, resulting in economic, social, and environmental damages.	It investigates the preparedness of Arab cities.	Due to inadequate capacity and funding, planning did not lead to implementation. Arab cities must alter their institutional frameworks in order to foster a culture of Disaster Risk Reduction (DRR) and collect and distribute knowledge for sound decision-making. Invest in early warning systems; create risk assessments and vulnerability maps by obtaining financing for social services and infrastructures; develop and enforce land use policies to reduce hazards and regulate construction rules for safer human settlements.
Energy self-sufficiency: An ambition or a condition for urban resilience?	[151]	Energy self-sufficiency appears to be one of the most important resilience factors for territories during and after a crisis.	It investigates the resilience–self-sufficiency duo in order to overcome the seeming simplicity of their connection, which tends to make self-sufficiency the horizon of territorial resilience. It examines urban technological systems using two resilience approaches: "functional" and "spatial".	Self-sufficiency is dependent on the ability to assure the reliability of the service. Providing services from the most critical infrastructures is a type of functional resilience that relates to "the capacity of the system to satisfactorily modify its functioning following a catastrophic event". The spatial resilience method enabled by meta-systems and smart shelters is aimed at creating a self-sufficient region capable of dealing with natural disasters.
Landslides-oriented urban disaster resilience assessment—A case study in ShenZhen, China	[152]	Urban disaster resilience research contributes to a better knowledge of disaster preventive and mitigation capabilities, as well as helpful benchmarks for robust city development.	Physical and social resilience were conceptualized as elements of urban catastrophe resistance to rainfall-induced landslides. In 2016, a Support Vector Machine (SVM) model was used to assess physical resilience, while a Delphi Analytic Hierarchy Process (Delphi-AHP) model was utilized to assess social resilience on a sub-district scale.	When physical resilience and social resilience were compared, physical resilience outperformed social resilience, demonstrating that the government should enhance urban management of social services and physical infrastructural development to boost social resiliency of urban disasters.
FLIAT, an object-relational GIS tool for flood impact assessment in Flanders, Belgium	[153]	Floods' socioeconomic, ecological, and cultural impacts must be examined, as well as the potential disruption of a society in terms of priority adaptation guidelines, measures, and policy suggestions.	a cross-platform Flood Impact Assessment Tool (FLIAT) was designed utilizing open-source software languages that can do parallel computing and a vector method coupled to a relational database	FLIAT can manage several comprehensive datasets with no loss of geometrical information and outlines the tool's development and performance.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Hindcasting Community-Level Damage to the Interdependent Buildings and Electric Power Network after the 2011 Joplin, Missouri, Tornado	[154]	Tornado-prone populations' resilience can be increased by using risk-informed decision-making methods. These tools can give critical information to community decision-makers, allowing them to explore a variety of mitigation and/or recovery methods for relevant sectors in a community, such as physical infrastructure, social and economic sectors.	A comprehensive spatial data set derived from the electric power company, along with a geographical wind speed model, component fragilities, and numerous other factors, such as the category of the power poles, age, and urban growth rate, were considered in this evaluation to identify the extent of the tornado's losses to the city's Electric Power Network (EPN).	A study has calculated the probabilities of power loss for each building in a city based on damage to electric poles and transmission lines. Decision-makers can use this information to increase community resilience. A structured cellular automata technique was used to determine the service area of substations and the route the electric power must take to reach demand nodes.
Measuring the Impact of Transportation Diversity on Disaster Resilience in Urban Communities: Case Study of Hurricane Harvey in Houston, TX	[121]	There have not been many quantitative studies that examine how physical infrastructure designs, and more especially transportation variety, affect urban connection and mobility in the setting of actual disasters.	It tries to analyze how the availability and distribution of transportation infrastructure might affect the disaster resilience of human-infrastructure systems in metropolitan settings since disaster resilience is viewed as a dynamic process before, during, and after catastrophe in different communities. It analyzed the hurricane Harvey resilience of several Houston neighborhoods and discovered that areas with more transportation diversity showed greater resilience in terms of their mobility both during and after the storm.	The findings can enhance urban planning and transportation design, particularly in light of climate change and other natural disasters.
Cyberpark, a New Medium of Human Associations, a Component of Urban Resilience	[155]	Resilience places a high focus on disaster preparedness and prevention, and infrastructure and information are two key connected industries. Public and free areas play a significant role in preventative infrastructure in cities.	This main focus is on how to incorporate the cyberpark into spatial planning and policy to improve the urban environment's resilience.	In order to highlight the significance of "the cyberpark's" physical shape and spatiality, this chapter focuses on the psychological and social functions that "the cyberpark" plays in remarkable occurrences. Information and communication technologies (ICTs) and urban open/public spaces are combined and examined in Cyberparks. In this way, they include aspects of informational architecture and infrastructure for prevention, and they make up important parts of urban resilience.
The projected impact of a neighborhood-scaled green-infrastructure retrofit	[156]	However, LID is often only applied and evaluated at the local level; very few research has examined the wider effects of GI at a bigger level. In actuality, the majority of GI performance calculators are only helpful at the site scale.	It tries to ascertain what the possible outcomes of a larger-scale GI retrofit of an existing suburban community for flood protection may be.	If all residential properties in the region switch to Low Impact Irradiation (LID) instead of traditional stormwater management methods, Sugar Land has the ability to annually catch 56 billion liters of runoff.
Seismic vulnerability assessment at urban scale: Case of Algerian buildings	[157]	Protecting people and property from the effects of a natural or industrial disaster is the primary goal of risk reduction operational and methodological techniques. Although it is impossible to expect to live in a risk-free environment, it is still feasible to lower this risk by using effective prediction and management techniques.	An integrated approach for assessing earthquake damage at the urban scale in Algeria is presented in this paper. Its primary goal is the suggestion of streamlined operational and scientific techniques to evaluate urban vulnerability and socioeconomic losses.	The outcomes of this earthquake scenario indicate that the area under study would suffer significant damages. The findings of this study will guide the local government's decision-making as it relates to the unique socio-environmental vulnerability situation at the Great-Blida urban scale. In order to achieve this goal, the study suggests a number of operational approaches that, depending on the demand for resilience-building, reduce seismic risk.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks	[158]	The complexity of securing the lifelines is projected to rise in response to contemporary issues including climate change and the aging of CIs, increasing the risk of failure-related damages and financial losses.	In order to measure and map flood resilience levels, this study proposes approaches that take into consideration critical infrastructure networks as risk propagators at various geographical scales.	The findings encourage the creation of creative plans and decision-making tools for fresh, resilient urban landscapes.
Mitigating climate change related floods in urban poor areas: Green infrastructure approach	[130]	It is crucial to recognize that the urban poor are both the most vulnerable group and a crucial component of mitigation measures. Although there are now mitigation strategies in place to decrease the effects of floods caused by climate change in urban poor regions, the deployment of green infrastructure as a mitigation approach has received little attention.	In order to lessen the effects of flooding caused by climate change, it looked at existing Green Infrastructure (GI) techniques in the urban poor neighborhood of Kibera (Kenya), Madurai (India), and Old Fadama (Ghana). The success of GI implementation was ensured by looking at how urban players deal with and resolve the crucial problems of governance, financing, and awareness.	In order to ensure the success of projects, it was discovered that GI needs a thorough grasp of the political, social, economic, and environmental elements of the urban poor population. The key is cohesive collaboration and full engagement of urban stakeholders.
Assessment of the hurricane-induced power outages from a demographic, socioeconomic, and transportation perspective	[159]	In the areas they affect, natural disasters have a terrible impact on the infrastructure and disrupt every facet of everyday life. First, an impact assessment is required to lessen the effects of extreme events.	It focuses on a two-step process to assess Hurricane effects on Florida's capital city of Tallahassee.	The results of this study can help emergency personnel identify vulnerable and/or crucial areas as well as those socioeconomic and demographic categories that were disproportionately affected by storms.
Analysis of tsunami disaster resilience in Bandar Lampung Bay Coastal Zone	[160]	According to its level of tsunami danger, Bandar Lampung comes in third.	This study analyzed the region's preparedness for a tsunami and the possible dangers of a tsunami disaster. The primary and secondary data collecting techniques were utilized in this study's methodology, and the field data were then subjected to quantitative analysis techniques such spatial analysis and descriptive analysis.	In the Gulf coast region of Lampung and Bandar Lampung, the level of readiness for the tsunami was still poor. There are still a lot of built areas and residences in communities that are either made up of fishermen or people who do not fish that are situated in a tsunami threat zone. The majority of residents are fisherman, and because the infrastructure is outdated and poorly maintained, the neighborhood has turned into a slum.
Integration of stress testing with graph theory to assess the resilience of urban road networks under seismic hazards	[161]	Even during natural disasters, transportation networks must be able to provide a reasonable degree of service to essential facilities.	It created a technique for determining a transportation network's resistance to environmental threats. This strategy contains five fundamental phases and combines graph theory with stress testing methods. A scenario set that covers a range of seismic damage potential for the network is established, resilience is evaluated using different graph-based metrics, topology-based simulations are performed, changes in graph-based metrics are assessed, and resilience is examined in terms of the topology of the entire network as well as the spatial distribution of critical nodes.	The findings support stakeholders in their evaluation of the topology-based resilience of transportation systems.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Flood hazard mapping in the floodplain of Malingon River, Valencia City, Mindanao, Philippines	[123]	Due to the loss of lives and livelihoods caused by flood dangers, the government began to think about the need for research aimed at reducing flood impacts and raising awareness to build more adaptable and resilient communities.	The combined technologies of Geographic Information System (GIS), Light Detection and Ranging (LiDAR)-derived Digital Elevation Model information system (DEM), and families of hydrologic models such as Hydrologic Engineering Center-Hydrologic Modeling System and -River Analysis System were used in this study (HEC-HMS and HEC-RAS). The goal was to calculate the amount and timing of precipitation–runoff interactions in the upstream watershed, as well as to perform two-dimensional hydraulic calculations in the Malingon River floodplain in Valencia City, Philippines.	The study's findings provided a foundation for making better informed decisions and making science-based suggestions in developing local and regional policy statements for more effective and cost-effective flood management techniques.
The Impact of Climate Change on Resilience of Communities Vulnerable to Riverine Flooding	[110]	The Federal Emergency Management Agency's Flood Insurance Rate Maps are insufficient for the changing requirements for public resilience evaluation and decision-making during the coming century, when the effects of climate change are projected to be considerable.	It created a methodology for flood hazard modelling to aid in assessing community resilience. This framework combines a hydrological model, which uses measured and/or remote sensed precipitation to simulate the hydrological processes in a community at a coarser resolution, with a hydraulic analysis module, which determines regional flood depths, velocities, and flooded areas at a temporal and spatial precision.	It demonstrates the probable effects of climate change on civil infrastructure in the twenty-first century and argues that these effects are not insignificant but can be controlled with the right engineering.
Planning and Urban Informality" Addressing Inclusiveness for Climate Resilience in the Pacific	[162]	The urban poor's housing stock in urban informal settlements has suffered significantly greater damage than in nearby formal city districts, according to the losses and damage caused by catastrophic weather events in just the past three years.	It discusses the nature and extent of urban development in the Pacific region by providing evidence of the unplanned settlements' rapid growth in low-lying coastal areas at risk of coastal erosion and sea level rises as a result of a number of factors, such as ineffective and expensive land registration systems;	In order to help practitioners, understand informality in the urban Pacific better and plan with it rather than against it, it offered a number of critical techniques.
New Strategies for Resilient Planning in response to Climate Change for Urban Development	[163]	Regulation and public–private partnerships are used to execute safety management for reducing flood damage.	In reaction to unusual weather, offer innovative approaches to land use and water management that enable waterfront areas to function as cities by providing amenities and public areas. This is based on the success of resilient projects in the Netherlands. The multidimensional approach for flood risk that has been established by the Dutch government is based on a response that is centered on spatial planning.	(1) A preventative plan tailored to the local property; (2) Developing spatial planning while taking disaster risk level and vulnerability into account; (3) Developing urban planning while taking flood hazards into account.
Resilient Urban Infrastructures—Basics of Smart Sustainable Cities	[164]	The concept of urban infrastructure resilience is articulated vocally and rigorously in conditional probability terms.	An interdisciplinary and complex method is used to describe the concept of quantitative resilience in urban design, operation, risk management, and hazard mitigation.	The critically important challenge of connecting physical and geographical (core) resiliencies with functional, organizational, economic, and social resiliencies is outlined.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Proposal for Holistic Assessment of Urban System Resilience to Natural Disasters	[165]	Most studies in the pertinent literature take each component independently. However, the goal of this research is to evaluate the urban system as a whole, considering all pertinent elements and their interconnections.	Options for evaluating the overall resilience of the urban system to natural disasters.	In order to identify crucial areas and system bottlenecks as the foundation for additional risk mitigation measures, this scheme is introduced as a mathematical graph model.
Spatial and temporal evolution of community resilience to natural hazards in the coastal areas of China	[120]	to strengthen the foundation for community resilience in China's coastal regions, which are the most economically and populated developed regions and where maritime catastrophes occur most frequently.	A community resilience index was created using social and economic data collected at the city level. 55 city-level indicators were broken down into 15 components using factor analysis.	Findings emphasized the importance of having a strong and developed economy, excellent education, and training programs to raise public awareness of disaster prevention and mitigation, adequate funding for vital infrastructure, particularly in the areas of transportation and communication, sound environmental policies to safeguard ecosystems and water resources, and extra care and budgets for disaster risk for vulnerable groups.
Spatial modeling of infrastructure resilience to the natural disasters using baseline resilience indicators for communities (BRIC)—Case study: 5 districts/cities of Bandung Basin Area	[166]	Measurements of resilience are helpful in determining a region's potential to endure a natural disaster. The BRIC (Baseline Resilience Indicators for Communities) approach may be used to assess community resilience to natural disasters. The social, economic, communal, institutional, infrastructural, and environmental variables all form part of this paradigm.	By utilizing geographic modeling to assess resilience to natural catastrophes while keeping an eye on infrastructure resilience, researchers were able to identify the main driving force behind this resilience trend.	The findings indicated that practically all urban regions, including Bandung and Kamahi City, had high levels of resilience due to their abundance of infrastructure items. However, to the district areas, several patterns of low and moderate resilience level are still present there. Roads are the main determinant of infrastructure resilience in this study field. Areas that are near to the road have a high resilience, while those that are farther away have a low resilience.
Virtual city for water distribution research in crisis management	[167]	Infrastructure data are important in our culture, yet studying critical infrastructures is challenging since studies on actual systems cannot be made public. Virtual cities are one possible solution to this issue.	a completely detailed virtual metropolis with roughly 900,000 people using GIS and other infrastructure modeling software was designed. The city is now being built, and it will include all essential infrastructures and their interdependencies, such as the gas network, agent's networks, and the electric power grid.	A resilience index based on the number of households without service has been utilized to compare various scenario occurrences, and the numerical findings have been reported.
Vulnerability assessment of urban community and critical infrastructures for integrated flood risk management and climate adaptation strategies	[12]	Flood risk management concerns must be addressed, as well as climate adaption measures.	The goal of this article was to provide an integrated framework for analyzing a metropolitan area's flood risk and climate adaptation capabilities, as well as essential infrastructures, in order to solve flood risk management challenges and suggest climate adaptation methods.	It developed a framework for improving policies and adaptation plans to boost urban communities' resilience to flood risk and weather-related disasters.
Toward more resilient flood risk governance	[168]	Effective and lawful flood risk governance can increase this social resilience to flooding. Flood risk management methods, and their effective execution, can be regarded as an essential prerequisite for resilience. Research in governance and law has the ability to offer fundamental insights into the discussion of how to increase resilience.	The governance structures are suited to the physical, socio-cultural, and institutional situation.	The prescriptive starting point of flood risk governance must be the subject of an open and transparent discussion between scientists and practitioners. Other requirements include a distinct line between roles and responsibilities, the creation of interconnection among actors, levels, and sectors through connecting mechanisms, and adequate information systems, both locally and globally.

Table A1. *Cont.*

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Spatial structure and evolution of infrastructure networks	[169]	While it is feasible to predict the functioning of these systems, their complexity makes assessing their contribution to economic development or resistance to hazard challenging. This shortcoming derives from our failure to identify significant general qualities that would allow us to simplify the process and so undertake probabilistic evaluations, or to recognize the underlying factors that regulate their evolution, allowing us to make sound future judgments.	It proposes an approach for generating spatial nodal layouts that share a variety of non-trivial characteristics with various sorts of real-world networks.	The algorithm-generated synthetic networks can be used in planning studies to evaluate how infrastructure can evolve in the future, such as analyzing alternative planning or policy scenarios, or in other scenario-based evaluations, such as hazard tolerance studies.
Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi, and Tokyo	[170]	It is critical to enhance the existing water management systems in order to provide high-quality water and decrease hydro-meteorological disasters while also protecting our natural/pristine environment in a sustainable manner.	It gives an outline of stormwater runoff management in order to advise future effective stormwater runoff measures and policies within the governance structure. Furthermore, the impacts of various onsite facilities, such as those for water harvesting, reuse, ponds, and infiltration, are investigated.	It establishes adaptation measures on a watershed scale to restore the water cycle and prevent climate change-induced flooding and water scarcity.
A network-based framework for assessing infrastructure resilience: A case study of the London metro system	[171]	It is critical to strengthen the resilience of large-scale infrastructures such as metro systems in order to meet the danger of natural disasters and man-made threats in metropolitan areas. Analysis is required to guarantee that these systems can withstand and contain unforeseen disturbances, as well as to create heuristic methodologies for directing the future construction of more resilient networks.	It gives a methodology for analyzing network topology, geographical organization, and passenger flow data in order to assess the resilience of the London metro system.	The framework provides important ideas for building resilience in present and future metro systems.
Enhancing City Resilience Through Urban-Rural Linkages	[172]	Urban populations in poor nations struggle to accumulate resources to resist a shock, and pressures gradually degrade resilience and raise population vulnerability over time. At the same time, communities are becoming increasingly susceptible owing to a lack of infrastructure, dispersed populations, disaster management capacities, and restricted livelihood prospects. Furthermore, a city is only resilient if the majority of its citizens can survive and recover from the consequences of a calamity.	Many cities have embraced the development authority approach (that is, local governments planning for urban regions as well as catchment rural areas).	It explores the interdependence of cities over villages and vice versa, as well as how these urban-rural links might be used to strengthen city resilience. It also uses case studies from India's development authorities.
Characterizing resiliency risk to enable prioritization of resources	[173]	The supply chain is critical to the resilience of our global economy at every level. Organizations must first understand and comprehend their supply chain.	Through geographic supply chain mapping, organization value (criticality, monetary value, loss of time) characterization, and reliance on each supply chain node, we build situational awareness.	These risk variables are interconnected rather than independent.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
Critical infrastructure interdependence in New York City during Hurricane Sandy	[174]	Using GIS mapping tools, this study determines the direct and indirect costs of Hurricane Sandy for each essential infrastructure sector. It also presents a Bayesian network as a method for examining the interconnectivity of essential infrastructure.	It seeks to examine Hurricane Sandy's effects from the aspect of interdependence across several key infrastructure sectors in New York City and to evaluate the interconnectedness of hazards brought on by such a hurricane.	The main sector from which hazards were spread to other industries was the power industry. The analysis of recent efforts to strengthen New York City's vital infrastructures following Sandy demonstrates that these efforts are mostly focused on creating hard infrastructures to reduce direct damages. They minimize the significance of cross-sector interdependence risk.
Systemic Vulnerability and Risk Assessment of Transportation Systems under Natural Hazards Towards More Resilient and Robust Infrastructures	[175]	The absence of redundancy, the protracted repair times, the challenges associated with rerouting, or the interdependencies that result in cascade failures make transportation infrastructure vulnerable. In terms of life safety, business interruption, access to emergency services and vital utilities, rescue efforts, and socioeconomic effects, their devastation might be quite disruptive.	An integrated approach for assessing the probabilistic systemic risk and vulnerability of utility and transportation networks is offered.	The short-term effects of seismic occurrences immediately following an earthquake are explicitly taken into account when calculating the systemic risk for the road network and port. Direct damage to road segments and bridges, as well as building and overpass collapses, can all result in road interruptions. Failures of dockside infrastructure and cargo handling machinery, interruptions in the provision of electricity, and building collapses can all impede harbor operations.
Developing a flood vulnerability index for a case study area in Melbourne	[176]	Various methodologies, such as historical loss data, vulnerability curves, and flood vulnerability indexes, have been used to assess and evaluate flood susceptibility that is the most widely used method among these approaches, and it has three components (hydrological, social, and economic) that taked into account the exposure, susceptibility, and resilience of any system.	It described the social component and its variables were used to calculate and analyze the Social Flood Vulnerability Index for Moreland City, which is located in northern Melbourne.	According to the created model, Glenroy, Coburg, Coburg North, Oak Park, and Gowanbrae are the most flood risk suburbs in Moreland City.
Measuring resilience to natural hazards: Towards sustainable hazard mitigation	[177]	A major concern in the sciences of hazard mitigation is measuring resistance to natural disasters.	The biophysical, built environment, and socioeconomic resilience components were operationalized for local jurisdictions in significant South Korean urban metropolitan regions using a confirmatory factor analysis. Significant geographical differences were found when the factor scores of the dimensions were mapped.	Urban regions that are densely populated and prosperous typically lack biophysical resilience. Some municipal governments that were grouped together turn out to be in various metropolitan regions. Given the regional heterogeneity and disparity in the resilience characteristics, coordinated and adaptable governance is required for long-term hazard mitigation.
Reinforcement of energy delivery network against natural disaster events	[178]	The electric power system is the most crucial of all metropolitan infrastructures affected by natural disaster occurrences. Most disaster relief activities rely solely on the availability of a steady and continuous supply of power. To establish power grid resilience against natural disasters, a detailed study of interrelations within the energy delivery system is needed initially.	It proposes a graph-theoretic framework based on fuzzy cognitive maps for modeling and analyzing the grid as an interconnected system of components connected by weighted and directed edges.	An optimization problem with constraints has been used to frame the discussion. The system is mapped onto the city's flood plain map, and analysis and optimization are conducted using abstract models.

Table A1. *Cont.*

Title	Reference	Research GAP/Motivation	Objective/Purpose	Result/Output
A framework for selecting a suite of ground-motion intensity maps consistent with both ground-motion intensity and network performance hazards for infrastructure networks	[179]	While in certain instances consistency with the exceedance curves of a performance measure may be more essential, efforts to choose a representative suite of scenarios, as reflected by weighted ground motion intensity maps, have historically focused primarily on consistency with the seismic hazard.	It uses optimization to pick a smaller set of ground motion intensity maps for a regional network of bridges, highways, and local roads. It then assesses the consistency with the ground motion danger. In the second stage, authors select a computationally efficient performance measure that is reflective of a metric of larger importance. The reduced suite is then evaluated to see how well it matches the performance measure exceedance curves.	Its findings show that we may reliably predict the exceedance rates of prospective ground motion intensity and performance metrics, such as the percentage change in average morning travel time 2–3 days following an earthquake, using a limited suite of re-weighted ground motion intensity maps. While we focused on seismic risk to urban road networks, our paradigm is applicable to analyzing network risk from a variety of hazards.
Sustainability of urban drainage management: A perspective on infrastructure resilience and thresholds	[180]	Urbanization, which increases urban runoff, and major population migrations, which generate changes in domestic emissions, are taken into account. Pollution licenses for aquatic bodies are used to impose restrictions on wastewater infrastructure.	To map residential discharge and urban runoff to wastewater treatment plant service regions, a land use-based accounting system paired with a grid-based database is created.	To develop more strong wastewater management under varied hazards, infrastructure resilience must be taken into greater account in urban planning and the linked sphere of urban governance.
The management of urban surface water flood risks: SUDS performance in flood reduction from extreme events	[181]	This study demonstrates the use of Geographic Information Systems (GIS) in improving the inter-related risk assessments of sewer surface water overflows and urban floods, as well as enhanced communication with stakeholders.	To provide a rigorous management approach to surface water flood hazards and to increase the resilience of urban drainage infrastructure, an innovative coupled 1D/2D urban sewer/overland flow model was created and tested in conjunction with a SUDS selection and location tool (SUDSLOC).	It highlights the numerical and modeling foundations of the combined 1D/2D and SUDSLOC method, as well as the application's working assumptions and flexibility, and certain limits and uncertainties. For an extreme storm event scenario, the relevance of the SUDSLOC modelling component in estimating flow and surcharge reduction advantages resulting from the strategic selection and positioning of various SUDS controls is also highlighted.
Zero cost solutions of geo-informatics acquisition, collection, and production for natural disaster risk assessment	[118]	Geo-informatics as the foundation of decision-making knowledge has proven to be crucial and necessary in assessing natural, technical, and man-made catastrophe risk. Commercial geo-informatics sources are typically expensive, particularly in poor nations and locations where living standards are low yet natural catastrophes occur frequently and inflict substantial losses.	discusses our experience with zero-cost geoinformatics acquisition, collecting, and semi-automatic production techniques utilizing free internet resources	Google Maps, Google Earth, and free and/or open-source tools such as QGIS (Quantum GIS), GRASS, SAGA, Monteverdi, Sextante GIS, and Orfeo Toolbox are all available.
Multi-criteria vulnerability analysis to earthquake hazard of Bucharest, Romania	[182]	In the face of an enormous growth in the financial importance of natural disaster damage, assessing and mapping the vulnerabilities of urban areas becoming critical in assisting experts and stakeholders in respective decision-making procedures.	To use a semi-quantitative method to construct a spatial vulnerability solution to seismic hazard. The model employs the analytical framework of a multi-criteria spatial GIS study.	It demonstrates a circular pattern, highlighting hot spots in Bucharest's historic center, and, from a sustainable development standpoint, demonstrates how spatial patterns influence the city's "vulnerability profile," by which decision makers can develop proper forecasting and mitigation strategies, as well as strengthen cities' resilience to seismic threats.
An alternative approach for planning the resilient cities in developing countries	[183]	Though several policy papers and research have voiced concern about incorporating disaster risk management concepts into development planning, the exact mechanisms of such integration at the spatial level are still being debated.	It proposes a method for incorporating disaster resilience in Quality of Life that is based on new urbanization models that may be reoriented toward attaining resiliency.	The Quality of Life with Disaster Resilience (QoLDR) measure integrates resilience challenges coming from urbanization as well as natural disasters. It also offers recommendations for changing urbanization and enhances adaptation, resulting in resilient urbanization.

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